THE

ROTHAMSTED MEMOIRS

ON

AGRICULTURAL CHEMISTR

AND

PHYSIOLOGY.

BY

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OF ROTHAMSTED, HERTS.,

AND

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ROTHAMSTED MEMOIRS.

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* Reference to these papers will show that Mr. R. Warington was a joint author.

ON THE

MORE FREQUENT GROWTH OF BARLEY

ON

HEAVY LAND.

BY

J. B. LAWES, F.R.S., F.C.S.

[*Read before the London Farmers' Club, February* 1, 1875.]

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LAST summer I received a pamphlet 'On the Growth of Barley in France,' by Mr. George Gibson Richardson. He commences by saying that the high average price to which barley appears permanently to have attained, interferes very seriously with the profits of the brewing trade, and renders it necessary that some attempt should be made to increase the supply, where such increase could be available for the English market. He goes on to say, that the land in Great Britain suitable for the growth of the finest barley is limited, that it is already so applied as far as practicable, and that on such land the farming has long been so good that an increased produce per acre is not to be looked for, nor is the result always satisfactory when such increase is obtained. But, he says, there is a country within sight of our own shores possessing every requisite for the growth of barley suitable for the choicest purposes of the English brewers; and he proceeds to explain the means he has taken to stimulate French farmers to increase the production of barley, and the success which has attended the supply to them of English-grown seed.

It is quite probable that any attempt to increase the yield of barley per acre, upon the best barley soils in this country, would be attended with a diminution in the quality of the grain. If, therefore, an effort is to be made to increase the national yield of the crop, it must either be done by growing it more frequently upon barley-soils, or by extending its growth upon soils which are not generally considered to be well suited to it.

I have for some time held the opinion that we have not taken full advantage of the peculiar adaptation of our climate to the successful growth of barley; and the appearance of Mr. Richardson's pamphlet has induced me to bring this subject before the members of the Farmers' Club. The present is, moreover, a very appropriate *time for its discussion.* Thus, after a wheat-*crop not more than fairly abundant*, the decline in price of the

grain has been very great. On the other hand, barley is, weight for weight, dearer than wheat. You need hardly be told that the climate of Great Britain is not so favourable for the production of good wheat as is that of many of the countries which supply us with that grain. The current prices in Mark Lane show that foreign wheats command higher rates than the produce of our own soil. The contrary is the case with barley. The best English is far superior to any foreign barley. The greater success of the British farmer, in this respect, with barley than with wheat, cannot be attributed to a greater expenditure of skill and capital in the production of the former crop, for he devotes equal skill, and more money, to the growth of wheat than of barley.

It may, therefore, be assumed that the climate of this country is very favourable for the production of good barley; and we have to consider this evening whether we have taken full advantage of this natural gift, or whether the extended cultivation of the crop on soils too heavy to be classed as "barley-soils," might not have a more prominent place in our agriculture.

To argue in favour of growing several corn-crops in succession may, at first sight, appear to be advocating an old practice which has been found wanting, and which has been abandoned in favour of the more modern system of rotation, or alternation of grain with fodder crops. To grow corn-crops in succession, each one inferior to the last, until the produce does not pay the cost of labour and seed, and then to allow the land to rest for several years, is a process totally different from that which I am about to propose. Artificial manures were almost unknown to the last generation of farmers. A knowledge of their effects, and abundant and cheap supplies of them, are essential to the system I have to advocate.

In bringing the subject of the more extended growth of barley in Great Britain before you this evening, I shall trouble you with figures as little as possible. They are the less necessary as a full report of our experiments with this crop has been published quite recently, in the 'Journal of the Royal Agricultural Society of England.' From the results there recorded, and from some which have been obtained since, I shall select a few as may be needed to illustrate and support my views. I do not anticipate any difficulty in proving to your satisfaction that, upon my land, which partakes much more of the character of a wheat than of a barley soil, crops of barley, good both in quantity and in quality, may be grown for many years in succession. I must leave it for you to decide whether your own soils are suitable for the trial, and to what extent it may be desirable and profitable to follow *such* a course in practice.

I propose to show—

First. That by the aid of artificial manures good crops of barley may be grown with profit upon heavy land, and much more frequently than according to our adopted systems of rotation.

Secondly. That on such land it is more advantageous to grow barley after another corn-crop, by means of artificial manures, than after roots consumed on the land.

The soil upon which my experiments have been carried on is a heavy loam, with a clay subsoil, resting upon chalk at a depth of from 8 to 12 feet from the surface. It is not artificially drained. Before commencing the continuous growth of barley, it had grown the following crops:—

1847. Swedish turnips, with dung and superphosphate; the roots carted off;
1848. Barley, unmanured;
1849. Clover;
1850. Wheat;
1851. Barley, manured with sulphate of ammonia.

The first experimental barley-crop was in 1852; and the land has been under barley ever since. Thus, in 27 years, there have been grown 1 crop of clover, 1 of wheat, and 25 of barley; the last 23 of which have been under careful experiment. Excepting on one plot, no dung, or animal manure of any kind, has been applied to the land during the whole of that period. In the following Table is given the average number of bushels of dressed corn per acre, over 23 years, 1852-74, inclusive, by several different manures.

Barley grown for 23 Years in Succession on the same Land.

Seasons 1852–1874. Rothamsted, Herts.

TABLE I.—DRESSED CORN PER ACRE, in BUSHELS.

Nos.	MANURES, PER ACRE, PER ANNUM.	Average 23 Years, 1852–'74.
		Bushels.
1	Superphosphate, alone	24¾
2	Superphosphate, and {200 lbs. ammonia-salts (or 275 lbs. nitrate soda)* .. ..}	49
3	Superphosphate, and {200 lbs. ammonia salts (or 275 lbs. nitrate soda)*, and sulphates potass, soda, and magnesia .. ..}	48¾
4	14 tons farmyard-manure	48⅞

* 400 lbs. ammonia-salts 6 years, 200 lbs. 10 years, 275 lbs. nitrate of soda 7 years.

200 lbs. of ammonia-salts, or 275 lbs. of nitrate of soda, each contain nitrogen equal to about 50 lbs. of ammonia. Although there are certain important distinctions between the actions of these two manures, we may assume for our present purpose that in the quantities named they are of equal manurial effect.

The average produce over 23 years, by superphosphate of lime alone, is only $24\frac{3}{4}$ bushels per acre per annum; showing, therefore, that there was an important deficiency of something, which was supplied in the case of each of the other experiments. The addition of ammonia-salts, or nitrate of soda, to the superphosphate, raises the produce to 49 bushels per acre per annum. The addition to this mixture, of sulphates of potass, soda, and magnesia, does not increase the produce further, giving only $48\frac{3}{4}$ bushels; whilst 14 tons of farmyard-manure have given $48\frac{7}{8}$ bushels. In fact, the last three experiments quoted give almost identical amounts of produce, and an average, over 23 years in succession, of more than 6 quarters of dressed barley per acre per annum.

That small quantities of artificial manure should, over such a long period, give as much barley as 14 tons of farmyard-manure applied annually is certainly a most striking fact. It may be useful, and will serve as some explanation of it, to point out briefly some of the most important points, both of distinction and of similarity, between the mixture of superphosphate of lime and ammonia-salts or nitrate of soda on the one hand, and farmyard manure on the other.

In round numbers, there have been removed annually, in corn and in straw, about $2\frac{3}{4}$ tons of produce per acre. Deducting from this the moisture it contains, there remain about $46\frac{1}{2}$ cwts., or rather more than $2\frac{1}{4}$ tons of dry or solid substance removed annually, and deducting from this again the mineral matter and nitrogen it contains, there remain about 44 cwts. of non-nitrogenous vegetable or combustible substance. In the dung very much more than this amount of vegetable matter has been returned to the land every year, but in the artificial manures none. Here then we have two parallel experiments, extending over a period of 23 years, in one of which much more non-nitrogenous or carbonaceous organic matter than was contained in the crop has been annually returned to the land in the manure, and in the other none, and yet the produce is equal in the two cases.

Now, I would ask whether you think it possible that such a soil as mine could stand such a drain as this for 23 years, or for 27 if we go back to the last application of dung, without showing a marked decline in the produce, if the plant depended upon the soil for its supplies of non-nitrogenous vegetable matter, or if that contained in the dung was at all essential to the result. The conclusion is, I think, obvious, that under the

influence of the superphosphate of lime and ammonia-salts or nitrate of soda, the growing barley was able to obtain its non-nitrogenous organic matter, amounting to between 90 and 95 per cent. of its total dry or solid substance, from the atmosphere, and not from the soil.

You will not fail to see the great importance of recognising this fact when you are told that you may depend upon artificial manures to grow more frequent corn-crops. Artificial manures contain but little, and the best of them no carbonaceous organic matter. If, therefore, they were active only so long as the plant could obtain sufficient organic matter from the soil, each succeeding corn-crop would cause a reduction of the condition of the soil, which could only be restored by the dung-cart. If, on the other hand, the organic matter is supplied by the atmosphere, the repetition of corn-crops by means of proper artificial manures may increase rather than diminish the condition of the land.

If we deduct from the 14 tons of dung, its water, its carbonaceous organic matter, and the extraneous mineral matter (soil, sand, &c.) which it always contains, there remains scarcely half a ton of mineral and nitrogenous matter. A good deal of this mineral matter is of comparatively little value. Of nitrogen there is from three to four times as much as in the 200 lbs. ammonia-salts, or in the 275 lbs. of nitrate of soda. But as the artificial manure and the dung have given equal crops, it is obvious that a given amount of nitrogen applied in the artificial manure is much more effective than the same amount supplied in dung.

There is an essential mineral constituent of a barley-crop which is supplied in dung, but not in the mixture of superphosphate of lime and ammonia-salts or nitrate of soda: this is potass. The crops grown by this artificial manure must, therefore, have obtained it from the soil itself. Of potass, the average crop of corn and straw has removed from 30 to 35 lbs. annually. It is obvious that, up to the present time, my soil has been capable of yielding the quantity required.

The dung has supplied about 1½ cwt. of potass annually, or about 34½ cwts. in the 23 years; and in the experiment No 3 the sulphate of potass has supplied an average of about 1 cwt. annually, or about 23 cwts. in the 23 years; yet neither the dung nor the artificial manure containing potass has given more barley than experiment No. 2 without potass. What may be the resources of other soils in potass it is not for me to say. It is, however, not at all likely that any farmer will grow corn, and remove both the straw and the grain, for so many years in succession from the same field as in my experiments, without bringing *the dung-cart into it;* and I may remark that if the

straw had been returned to the land, I might have taken more than 50 crops of barley in succession, without taking from the soil as much potass as I have done up to the present time.

The same kind of argument is applicable, but in a higher degree, in the case of silica. The straw of a barley-crop contains about five times as much silica as the grain; so that if the straw were periodically returned to the land in the form of dung, the exhaustion of that substance would be more gradual than that of potass. So also with other constituents.

From the facts I have brought before you, it may I think be concluded, that upon heavy soils, with a subsoil of clay, full crops of barley may be grown by the use of an artificial manure containing superphosphate of lime, and nitrogen either in the form of nitrate of soda, ammonia-salts, or Peruvian guano.

The next point is to show that barley may be grown not only in full quantity, but of good quality, by artificial manures used for many years in succession on the same land. The following Table (II.) shows the average weight per bushel of the barley grown by superphosphate of lime, and salts of ammonia or nitrate of soda, over the first 8 years, the second 8, the last 7, and the total period of 23 years.

Barley grown for 23 Years in Succession on the same Land.

Seasons 1852–74. Rothamsted, Herts.

TABLE II.—WEIGHT PER BUSHEL of DRESSED CORN.

No.	MANURES, PER ACRE, PER ANNUM.	First 8 Years, 1852–'59.	Second 8 Years, 1860–'67.	Last 7 Years, 1868–'74.	Total 23 Years, 1852–'74.
		lbs.	lbs.	lbs.	lbs.
2	Superphos., and {200 lbs. ammonia-salts (or 275 lbs. nitrate soda*)}	51	54¼	55½	53½

It is seen that the average weight per bushel of the barley was higher during the second than during the first 8 years, and higher still during the last 7 years of the 23. It is probable that the increase is in great part due to more favourable ripening seasons during the later years; but whatever may be the cause, it is clearly shown that when barley is grown by proper artificial manures, even for many years in succession on the same land, it does not deteriorate in quality.

Samples of the barley grown last year by a great variety of

* *400 lbs.* ammonia-salts 6 years, 200 lbs. 10 years, 275 lbs. nitrate of soda *7 years.*

artificial manures were exhibited, and in Table No. III. the produce per acre, and the weight per bushel, in each case, is given.

TABLE III.—PRODUCE, and WEIGHT PER BUSHEL, of BARLEY GROWN in 1874. ROTHAMSTED, HERTS.

No.	MANURES, PER ACRE, PER ANNUM.	Dressed Corn per Acre.	Weight per Bushel.
	Barley grown continuously, 23rd year, 1874.		
		Bushels.	lbs.
1	Superphosphate, alone	21 3/8	55
2	Superphosphate, and 200 lbs. ammonia salts	42 3/8	54 3/4
3	Superphosphate, and 275 lbs. nitrate soda	53 7/8	54
4	Superphosphate, and 1000 lbs. rape-cake	48 3/8	57 1/2
5	Superphosphate, and {200 lbs. ammonia-salts, and sulphates potass, soda, and magnesia .. ..}	49 5/8	57 1/2
6	Superphosphate, and {275 lbs. nitrate soda, and sulphates potass, soda, and magnesia .. ..}	51 3/8	57
7	Superphosphate, and {1000 lbs. rape-cake, and sulphates potass, soda, and magnesia .. ..}	49 3/8	57
	Barley, unmanured, after Barley, and after Clover.		
8	Barley after barley	32 7/8	57 1/2
9	Barley after clover	58 1/8	56 1/4

I took the liberty of forwarding some of the samples to Messrs. Bass for their opinion upon them. In answer, they said that all were suitable for malting. No. 1, grown by superphosphate of lime alone, they considered the best ripened, and the most kindly in appearance; and, after that, No. 4, grown by superphosphate and rape-cake, which, it will be seen, gave more than 6 quarters of barley, with a weight per bushel of 57½ lbs. Messrs. Bass go on to say that "the barley of this country possesses so decided an advantage in size over the barley of other countries, that we have been long surprised more attention has not been paid to this cereal. We cannot but think the time will come, and that shortly, when agriculturists in this country will see the advantage in placing a greater proportion of land under barley."

We now come to the important question of cost. I thought it *desirable to obtain estimates* from other, and independent,

sources, of the cost of some of the ordinary tillage operations. I am indebted to a number of practical farmers, residing in various counties, for answers to the following question—What is the cost of cultivating an acre of barley, of 6 quarters per acre, the barley following a previous corn-crop; the estimate to include every mechanical operation except hoeing, and to exclude rent, rates, seed, and manures?

The difference in the estimates was rather wide, varying from 45*s.* to 65*s.* I propose to adopt the highest, as I should prefer that, in the matter of cost, my estimate should be above rather than below that of others:—

Cost per Acre.

	£	*s.*	*d.*	£	*s.*	*d.*
Rent and rates	1	12	0			
2½ bushels seed, at 40*s.*	0	12	6			
2¼ cwts. nitrate of soda, at 16*s.*	1	16	0			
3½ cwts. superphosphate, at 6*s.*	1	1	0			
Hoeing twice	0	7	0			
Ploughing, harrowing, drilling, harvesting, thrashing, and taking to market	3	5	0			
Total				8	13	6

Produce per Acre.

	£	*s.*	*d.*	£	*s.*	*d.*
6 quarters of barley, at 44*s.*	13	4	0			
3 bushels of offal corn, at 4*s.*	0	12	0			
1½ ton straw, at 20*s.*	1	10	0			
Total				15	6	0
Cost				8	13	6
				6	12	6

It would be quite possible, by adding to the expenses on one side, and reducing the selling prices on the other, to bring out a very different balance. For instance, I have valued the straw at 20*s.* per ton; which would not be too much if sold off the land; but it will most frequently be used on the farm, in which case the consuming, or manure value only, could be adopted. Still, under the most unfavourable arrangement of the figures, there would appear to be a good profit on the operation. It is for others to consider how much it would probably be under their own particular circumstances.

I will now describe briefly some results obtained in another field. It has not been under careful experiment, and I am unable, therefore, to give the amounts of produce previous to the last two years. It has, however, been cropped as follows:—

1864. Red clover.
1865. Wheat, with artificial manures.
1866. Mangolds, with dung and artificial manures; crop removed from the land.
1867. Wheat, unmanured.
1868. Oats, with artificial manures.
1869, 1870, 1871, and 1872. Barley, with artificial manures.

Thus, prior to 1873, it had grown 6 corn-crops in succession, the last five with artificial manures. In 1873 it was unmanured, one-half being in barley and the other half under clover, sown with the barley in the previous year. The object in sowing red clover was to ascertain whether, after a succession of corn-crops grown by artificial manures, there remained any residue suitable for the growth of red clover. In 1874 the whole field, both barley and clover ground, was again sown with barley, and the produce was in the two years as follows:—

TABLE IV.—BARLEY after BARLEY, and after CLOVER, all Unmanured.

		Produce per Acre.
1873	Barley	31 bushels.
1874	Barley after barley	$32\frac{3}{4}$ bushels.
1873	Clover-hay	54 cwts.
1874	Barley after clover	58 bushels.
	Barley after clover more than after barley	$25\frac{1}{4}$ bushels.

Thus, after 6 corn-crops since the application of dung, and the last 5 grown by artificial manures, in 1873 the produce of barley without manure was 31 bushels, and that of clover 54 cwts. of hay. In the next year, 1874, again without manure, the produce of barley was, after barley $32\frac{3}{4}$ bushels, and after clover 58 bushels; or $25\frac{1}{4}$ bushels more after the clover than after the barley.

An outgoing tenant who had taken a wheat crop, an oat crop, and 4 barley crops in succession, with artificial manures alone, would stand a poor chance of establishing a claim for unexhausted manures. Yet, without any further application of manure, the land so treated has yielded $2\frac{3}{4}$ tons of clover-hay, and $7\frac{1}{4}$ quarters of barley. These facts show that the current opinion as to the exhaustion of the soil by corn-cropping requires some *modification, at any rate* in the case of heavy land

on which full crops have been grown by means of suitable artificial manures.

It cannot for a moment be supposed that any one cultivating a large farm could devote more than a certain limited proportion of the whole to the growth of barley. Even with the aid of steam-cultivation wet springs would occasionally reduce the area pre-arranged for the crop. Assuming, however, it to be concluded, that it would be profitable to extend the area under barley on heavy land, I would venture to suggest the following as a rotation worth trying.

I would divide the land into twelfths, as follows:—

One-twelfth mangolds;
One-twelfth beans;
One-twelfth red clover;
Two-twelfths wheat;
Seven-twelfths barley.

Or, assuming a farm of 600 acres, there would be—

50 acres mangolds;
50 acres beans;
50 acres red clover;
100 acres wheat;
350 acres barley.

It would certainly require great attention to the cleaning of the land, if so large a proportion as three-quarters of the farm were in corn. If this difficulty can be got over, I see no reason why such a course of cropping should not be more profitable than that fixed by the ordinary rotation.

That some attempts have been made to wander from the orthodox rotation of crops is evident from the fact that I occasionally receive visits from farmers who come to see whether the experimental corn-corps at Rothamsted still continue to flourish; and I find from them, on inquiry, that too much, rather than too little, success has been the occasion of their journey. Their friends and neighbours tell them it may be all plain sailing just now, but retribution is surely not far off. They dangle the spectre of exhaustion before their eyes, and terrify them with the prospect of the evil consequences which must, sooner or later, overtake them. I have reason to think, however, that an inspection of my fields tends to reassure them; and that they return home at any rate with the consolation that, if barrenness is to follow the more frequent growth of corn, it will certainly make its appearance in the fields of Rothamsted before it does in their own.

Not long ago, there was some discussion in this room as to the

length of time successive corn-crops might be grown, and your President observed that, with deep cultivation, and the use of artificial manures, corn might be grown for 25 years. In the experimental wheat-field at Rothamsted the 37th crop since the application of farmyard-manure, and the 36th corn-crop, is now gowing; and in the experimental barley-field 28 crops have been taken since the application of farmyard-manure, of which 26 have been corn-crops, and 25 of them in succession. In both fields the cultivation of the land has been very superficial, being conducted according to the ordinary practice of the district 40 or 50 years ago. Doubtless subsoiling, or deeper cultivation, would in some cases largely increase our produce, and in others lessen the amount of manure required to obtain it. But to adopt either would sacrifice that which, up to the present time, has given the Rothamsted experiments a position which no other field-experiments can lay claim to, namely, that they are carried on year after year without change, either in the mechanical cultivation of the land, in the description of crop grown, or in the manures applied.

If some important constituent is wanting, the crop must necessarily decline. The barley grown by superphosphate alone has shown a very marked decline in produce during the second half, compared with the first half of the period. In other cases, where the proper manures have been applied, the average produce over the second half of the period is equal to that of the first half. From this it may be concluded, that any decline in produce will take place at any rate only very gradually, and that the time when the land will no longer grow good crops of barley must be very remote. After 20 years, the plot which had received 14 tons of farmyard-manure annually during that period was divided, and the application was then stopped on the one-half, but continued on the other. During the subsequent three years, although the produce on both portions has been large, it has been considerably less where the application was stopped than where it was continued. Still, it may be expected that 20, or 30, or more years will elapse, before the residue from the previous applications of dung is exhausted.

The subject of how long corn-crops may be grown is obviously one of great scientific interest; but the amounts of produce shown in the Tables, and the quality of the samples exhibited, are sufficient to show that, on heavy land, and with proper artificial manures, crops of barley which meet all the requirements of practice, both as to quantity, and quality, may be grown for many years in succession.

It will be useful to state the course of operations which may

be advantageously followed by those who decide to grow barley more frequently after a previous corn-crop.

Cultivation.

The land should be ploughed up as early as practicable in the autumn, and should not be touched again until it is dry enough to sow in the spring.

Time of Sowing, and Quantity of Seed per Acre.

The sowing should be in the last week in February, or as soon as possible afterwards. A good tilth is essential; it is vain to expect to grow a good crop of barley without it, especially when artificial manures are used. The quantity of seed per acre may be 2½ bushels if sown early, increasing to 3 bushels as the season advances.

Manures.

Nitrogen is an essential constituent in an artificial manure for barley. It can be purchased in nitrate of soda, sulphate of ammonia, or Peruvian guano. Feeling unable to recommend guano without some assurance as to its composition, I wrote to Messrs. Schröder and Co., the agents for the sale of Peruvian guano in this country, stating my difficulty, and in reply they write as follows:—

". . . . The importations of guano from the Guanape and Macabi Islands, during the time the agency has been in our hands, have averaged nearer 13 than 12 per cent. of ammonia. The quality from both islands has moreover been so even and uniform, that cargoes analysing anything below 12 per cent. of ammonia have been quite the exception."

It is very satisfactory to find that the present supply of Peruvian guano is so good and uniform in quality. If Messrs. Schröder and Co. would comply with a suggestion I have made, and state in their advertisements that they would not send out raw guano containing less than 12 per cent. of ammonia, nothing further could be desired.

In my experimental field, nitrogen equal to 50 lbs. of ammonia is required to grow 6 quarters of barley over an average of seasons. About this amount of nitrogen (rather less) would be supplied in the quantities of nitrate of soda, or of sulphate of ammonia, or of Peruvian guano containing 12 per cent. of ammonia, given in the first column below, and slightly more in the mixtures of them given in other columns:—

	If used Separately.	If used in Combination.	
	Cwts.	Cwts.	Cwts.
Nitrate of soda	2¼	1¾	1½
Sulphate of ammonia	1¾		
Peruvian guano	3½	1	1½

When nitrate of soda or sulphate of ammonia is used, without guano, about 3 cwts. of superphosphate, per acre, should also be employed.

When Peruvian guano is used alone, no superphosphate need be applied. When 1¾ cwt. of nitrate and 1 cwt. of Peruvian guano, or 1½ cwt. of each, is used, 1 cwt. of superphosphate, in addition, will be sufficient.

As in all cases of ordinary farming the straw will go back to the land periodically in the form of dung, it is probable that, under such circumstances, smaller quantities of artificial manure may be required to yield the same amount of crop, than were found necessary in my experimental field. On a farm of 600 acres, under the twelve-course rotation which I have suggested, there would probably be about 2000 tons of dung made annually. This would allow 20 tons, per acre, for the 50 acres of mangold, 10 tons, per acre, for the 50 acres of beans, and 10 tons, per acre, for the 50 acres of red clover. The wheat following the beans or the clover would require no artificial manure. The grain-crop following the mangolds might require a small dressing of nitrate of soda in the spring, say 1 cwt. per acre. For the barley succeeding this, or succeeding the wheat after clover or beans, 1½ cwt. of nitrate of soda, with 2 cwts. of superphosphate, or 2¼ cwts. guano without superphosphate, might be sufficient. For the next crop of barley (the third corn-crop) the quantities given in the foregoing Table might probably be required. A knowledge of the soil and climate, and practical experience in the use of the manures, are, however, essential to determine the exact quantities of manure required to produce full crops. But the cultivator must bear in mind, that a deficiency of produce is more likely to be due to a deficiency of nitrogen than of any other substance.

Mode of Application of the Manures.

In my experimental fields the artificial manures are sown broadcast by hand, and ploughed or harrowed in before the seed is sown; and to ensure the necessary regularity of distribution,

the quantity is divided, and the ground sown two or three times over. In the fields under ordinary farm-cultivation, the manures are mixed together and sown immediately behind the drill, once over only; and the seed and manures are harrowed in together. A machine-distributor which will sow small quantities of artificial manure with perfect regularity is much wanted, and has not yet been produced.

Weeds.

I will assume that a farmer intending to grow several corn-crops in succession starts with his land clean; aud being so, it is by no means difficult or costly to keep it clean. Each description of soil has its own prevailing weeds, and they should be watched very closely. Charlock is the great weed of this district, and the corn-fields are yellow with it when it comes into blossom. It is, however, not difficult to keep it under. Wild oats are the most troublesome of our weeds, and their appearance in the crop should be most carefully watched. If they are only seen here and there, the farmer may think it scarcely worth while to have them taken out; but the next year they will probably be found to have increased a hundredfold, and then pulling them out is almost impossible. They shed their seed before the barley is ripe, and will not grow by any autumn cultivation; so that if once they have gained the ascendency, nothing remains but to cease growing corn, and to clean the land.

Freedom of Cropping.

If every farmer were bound down by a stringent law not to grow two corn-crops in succession, and the law were unalterable, we should be discussing a subject this evening which could have no practical bearing. There is, I think, an impression gaining ground among landlords, land-agents, and tenants alike, that a greater latitude in cropping might be mutually beneficial. Landlords are, however, timid: they say, we have done very well under the old customs, why should they be changed? Land-agents are also timid, as well as wise in their generation: they say, if greater latitude be granted to the tenant, and any difficulty should afterwards arise about the letting of the land, we shall be told by the landlord that this is what comes of your absurd innovations.

When I addressed you nearly five years ago in this room, on the subject of *Unexhausted Improvements*, I pleaded on behalf of the tenant-farmer for greater freedom of cropping. I said I thought a tenant holding a lease should be left unrestricted in *his cropping, provided* he gave up the land at the end of his

term with a due proportion of corn and fallow crops. I am disposed to think, however, that little or no injury would be done to the letting-value of the land, if a considerably larger proportion of it were given up under corn, provided it were not a light-land or a stock-farm, provided neither roots nor straw were sold, and provided the corn-land were given up sufficiently clean to grow another corn-crop.

Having said so much on behalf of the tenant, I will say this on behalf of the landlord. If he relax covenants in regard to cropping, he should make them much more stringent in regard to weeds. If the land under corn be not kept clean, the landlord should have power to clean it at the expense of the tenant while the crop is growing, or to recover damages in some way which will secure the object in view, namely: that the corn-land shall be given up in a condition as to cleanliness, such that the incoming tenant may with advantage take another corn-crop from it.

If barley is to be grown more frequently, it is obvious that some other crop must either be excluded from the rotation or only be grown at longer intervals. Now, the root-crop appears to me to be somewhat out of place on heavy land. When such land is not clean enough to grow corn, a root-crop, or a summer fallow, may be advantageous. But if the land be clean, I submit to your consideration whether it would not be more profitable to grow barley by the direct application of artificial manures, than by the indirect process of manuring for the growth of a root-crop?

It would occupy too much time and space to discuss fully the exact position which a root-crop holds in a rotation; involving as it does the question of the production of meat and manure, by the consumption of the roots and other food. I will confine myself to directing attention to the results of some experiments which have led me to place a lower value upon roots as a heavy-land crop, than modern practice has assigned to them.

In a field devoted to the continuous growth of turnips, it was decided, after 10 crops of roots had been removed, to grow barley for the purpose of ascertaining whether, by the growth of the turnip, any residue had been accumulated within the soil which was suitable for the growth of barley. For instance, as silica is taken up in very small quantity by the turnip, but very largely by barley, it was possible that during the 10 years of the growth of the turnips it might have accumulated within the soil in a very favourable condition for being taken up by the barley, in combination with ammonia, for example.

Three unmanured barley-crops were taken in succession after

the turnips. The average produce of the barley after 10 crops of turnips, manured during the last 8 years by a liberal mixed mineral manure, was 20 bushels per acre; and where the turnips had received the same mineral manure, with some ammonia-salts also, the average produce was 22 bushels per acre. Over the same 3 years, the average produce of barley without manure, in the field where barley was growing continuously, was, after 3 preceding corn-crops, 31½ bushels, or 11½ bushels more than after the 10 crops of turnips. The amount of produce of the unmanured barley after the mineral-manured turnips did not vary more than 1 bushel per acre in the 3 years. The second of the 3 crops was grown in the very productive year of 1854, but amounted to only 19½ bushels; whereas, in the same season, the produce without manure in the field where barley was growing continuously was 35 bushels, though following 4 preceding corn-crops. In the same field, the superphosphate of lime alone gave 40½ bushels; and several of the artifical mixtures containing nitrogen gave nearly 8 quarters per acre.

The conclusion to be drawn from these curious results is that, independently of the excess of manure applied for the growth of the turnip, it leaves no residue suitable for the growth of barley; but, on the contrary, it exhausts the soil of what is required for the barley far more than does the growth of barley itself. Compare this with the produce of barley after clover, already referred to, and shown in Table IV., and it will be seen how very different is the position which clover and roots hold in a rotation.

It may be said that in ordinary practice the turnips are consumed on the farm, or even in the field which grew them, and hence much of what they take out of the land is restored to it. This is perfectly true. But I would ask whether, if the turnip leaves no residue suitable for the barley excepting the excess applied for the roots, and merely converts a portion of the food which would grow barley into turnip, to be consumed by animals for the reproduction of manure, would it not, in the case of heavy land, be more economical to convert such food directly into barley, without the intervention of the roots?

Another field has been devoted, for nearly 28 years, to experiments on rotation. The course of cropping has been turnips, barley, clover or beans, and wheat. The turnips alone are manured, and on the portion to which I am about to refer they are all fed on the land. The manure applied per acre, for each turnip-crop, has been a mixture of superphosphate of lime and salts of potass, soda and magnesia, with, in addition,

2000 lbs. rape-cake,
200 lbs. ammonia-salts.

The average produce over 6 rotations has been

Swedes, 12 tons,
Barley, 47 bushels,
Beans, 24 bushels,
Wheat, 33 bushels.

Let us compare this result with that obtained from the same amount of manure applied directly for barley in the experimental barley-field. 1000 lbs. of rape-cake have given, over 20 years, an average of 45 bushels per acre per annum. This used twice gives, therefore, 90 bushels for the use of 2000 lbs. of rape-cake. Again, mixed mineral manure and 200 lbs. of ammonia-salts (as also used in the rotation experiment) has given, over 20 years, an average of 46 bushels. We have, therefore, in all 136 bushels of barley produced by the use, on 3 acres, or in three years, of 2000 lbs. of rape-cake, 200 lbs. ammonia-salts, and mixed mineral manure.

In the rotation experiment, the same amount of manure grew in the first year 12 tons of swedes, for which nothing was received but the increased value of the animals consuming them. There was left, therefore, some charge for expenses, besides the cost of the manures, against the 3 succeeding crops; which were, 47 bushels of barley, 24 bushels of beans, and 33 bushels of wheat; whereas, when the same amount of manure was applied directly for the growth of barley, there was no extra charge against the crops as when grown after the roots, and 136 bushels of barley were obtained.

It may be said, that the injury done by the sheep consuming the roots on the land accounts for the comparatively small effect of the manures in the rotation experiment. No doubt they do injury, and this is one of the great objections to the growth of a large area of roots upon heavy land. This will not, however, account for the following facts:—

In the very hot and dry season of 1868, the root-crop in the rotation experiment entirely failed, but the succeeding barley-crop was only 42 bushels; whilst, one-third the quantity of manure, applied directly for the barley in the experimental barley-field, gave nearly 45 bushels.

In the rotation experiment, there has obviously been a much less result from a given amount of manure, than in the experimental barley-field. The exact explanation of the fact is not quite clear. Some of the nitrogen of the rape-cake and ammonia-salts has, no doubt, been lost by winter drainage, and some retained by the soil in such a condition of combination or distribution as to be only very slowly available for succeeding crops. *At any rate, we learn* that artificial manures give a much

better result when they are applied not long before active growth commences, and that, on heavy land, they can be more profitably used directly for the growth of barley than for roots to be succeeded by barley.

The great value of root-crops upon light land, and even upon some of the heavier soils where the climate is comparatively moist, has led to their cultivation upon land, and under climatal conditions, which are more suitable for the growth of grain. Added to this, there is a sort of undefined opinion prevailing with many farmers, that the manure produced by animals acts in some mysterious way, quite different from artificial manures, and hence they are afraid to trust too much to the latter substances.

The results obtained in the experimental field at Rothamsted show conclusively to what a great extent artificial manures may be relied upon to produce full crops of barley, of good quality, under what may be considered by no means favourable conditions as to tillage. There is no reason to doubt that, with the improved methods of cultivation now so much practised, the results I have laid before you this evening may be exceeded; and if the suggestions I have put forward be adopted, the brewers will not long have to complain that they are compelled to seek in other countries for the supply of barley which may be grown with profit on our own soils to a much greater extent than hitherto.

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ON THE

VALUATION

OF

UNEXHAUSTED MANURES.

BY

J. B. LAWES, F.R.S., F.C.S.

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ON THE

VALUATION OF UNEXHAUSTED MANURES.

CONTENTS.

ON April 4, 1870, I read a Paper before the London Farmers' Club, on the "Exhaustion of the Soil, in relation to Landlord's Covenants, and the Valuation of Unexhausted Improvements." The object of the first part of that Paper was to point out and illustrate the difference between those properties of the soil which are known under the term of "*condition*," and those which are included under the term *natural*, or *standard fertility*.

I defined *condition* of land to be due to the accumulation within the soil of manurial matters which may be withdrawn, or reduced, by cropping, within a comparatively short period of time. *Condition* was stated to be a quality dependent on the expenditure of the tenant; and, subject to the terms of his holding, may be considered to be his property.

The *natural* or *standard fertility* of a soil, on the other hand, was the property of the landlord; upon it depended, in a great measure, the amount of rent he was able to obtain for his land; and although this natural fertility was not absolutely inexhaustible, it was very little liable to injury from any system of agriculture which, so far as present appearances enable us to judge, had any prospect of prevailing in this country.

The second part of the Paper related to the question of the valuation of unexhausted manures; and, taking into consideration the great difficulty in laying down rules which would be generally applicable for the estimation of the productive capability, and consequently of the money-value, of the residue of the manures which have already yielded a crop, I suggested whether it would not be possible to confine the valuation to what was above ground, and had a recognised money-value, and, in so doing, to do full justice to the outgoing tenant.

About the time that that Paper was read, Parliament was discussing Mr. Gladstone's Irish Land Act, which afterwards became the law of the land. Under that Act an outgoing tenant is entitled to claim compensation for "tillages, manures, or other like farming works, the benefit of which is unexhausted at the time of the tenant quitting his holding." The Act is very explicit in all that relates to the legal machinery by which claims may be tried or established; but it gives no information as to what constitutes unexhausted value, or how that value is to be estimated.

It could hardly be doubted that on a subject so complicated, and in regard to which the best authorities might differ in opinion very widely, much litigation would take place. Extravagant claims have been put forward; and, if current report may be trusted, there is considerable dissatisfaction with the working of the Act among the Irish tenantry.

In 1873, an English gentleman, who had been the assignee of a lease granted to a previous tenant by the late Duke of Leinster, made, at the expiration of his term, very large claims upon the landlord for unexhausted tillages and manures. The case was tried before the Chairman of Quarter Sessions; and the judgment being adverse to the tenant, he appealed, and the cause was then heard by the Lord Chief Justice of Ireland. On that occasion I was present as a witness for the defendant; and I had ample opportunity of observing how great were the difficulties with which both the Judge and the opposing counsel had to contend. On my return to England, I wrote a pamphlet on 'Unexhausted Tillages and Manures, with reference to the Landlord and Tenant (Ireland) Act.' Part of the Paper had reference to the trial, and had, therefore, only a local and temporary interest. The remainder was devoted to an attempt to place a value on the unexhausted residue, under various circumstances, of the

most important of the manures which are likely to become the subjects of claim for compensation.

In reference to this subject, the Committee on "Unexhausted improvements" appointed by the Council of the Central and Associated Chambers of Agriculture, have done good service in collecting particulars of the allowances to the outgoing tenant for purchased cattle-food and manures, and other improvements, according to the established custom in different counties and districts.

Further, it is now a much-debated question, whether there should not be legislation in regard to England and Scotland, as already there is for Ireland, to secure to the outgoing tenant compensation for his unexhausted improvements; and, among others, especially for the unexhausted residue of purchased feeding-stuffs and manures.

It seems desirable, therefore, at the present time, to pass in review the state of existing knowledge on the subject of the value of such unexhausted improvements, and to compare the results arrived at by different methods, or on different bases of valuation. Accordingly, I propose to consider the basis, and the results, of the estimates of the value of the unexhausted residue of purchased (or saleable) feeding-stuffs and manures—

First: As set forth in my Paper on 'Unexhausted Tillages and Manures with reference to the Landlord and Tenant (Ireland) Act.'

Secondly: According to the established custom of various counties and districts, as recorded by the Committee on Unexhausted Improvements appointed by the Council of the Central and Associated Chambers of Agriculture.

Thirdly: Confining the valuation to what is above ground, and has a recognised and easily-ascertainable money-value.

Section I.—*Valuation of the Unexhausted Residue of purchased Feeding-stuffs and Manures, founded on the original Manure-value of the Article, and on the results of direct experiments, and of common experience, with different Manures.*

In the first place, I propose to direct attention to some of the data furnished by my experiments at Rothamsted, in regard to the amount, and to the condition, of the unexhausted residue left in the soil by different descriptions of manure; and to attempt to construct a scale of valuation for different manures, founded partly on those data, and partly on the recognised experience of practical agriculture.

Manures.

Before considering the question of unexhausted manures, it will be well to say a few words on the action and value of

manures generally, and especially on the difference in the actioı and value of different descriptions of manure.

The term *manure* includes a great variety of substances which, when applied to the soil, increase the growth of crops Formerly, the only manure employed was that produced bỹ animals consuming food, and using litter, which were exclu- sively the produce of the farm itself. Modern agriculture ha: greatly altered this state of things. We have now a long list o manures, derived from sources external to the farm itself, whicl are in common use by farmers.

The following is an enumeration of the most important o the manures, the unexhausted residues from which are likely t(become the subjects of claim for compensation :—

1. Manure produced from purchased (or saleable) feeding- stuffs.
2. Farmyard, or town-stable, manure.
3. Rapecake (or other cake) used as manure.
4. Bones.
5. Nitrate of soda.
6. Sulphate of ammonia.
7. Superphosphate of lime, made from mineral phosphates.
8. Guano, in its natural state, or manufactured.
9. Other manures of more or less unknown composition.*
10. Liming, chalking, marling, &c.

The difference in the price at which the different items o purchased manure in this list can be brought upon the farm i: very wide indeed.

By way of illustration, it may be assumed that town-mad(dung will, in the majority of cases in which it is largely used cost the farmer about 7*s*. 6*d*. per ton delivered on his farm Nitrate of soda will, however, cost him, say 15*s*. per cwt., some times more and sometimes less. Thus, he finds it worth hi: while to give about as much for 1 cwt. of nitrate of soda, as fo 2 tons of stable-dung; or, in other words, about 40 times a much for an equal weight of the one manure as of the other.

Sulphate of ammonia is dearer than nitrate of soda; and al though it is not purchased to any great extent by the farmer, i is much used in the manufacture of mixed artificial manures.

Again, Peruvian guano contains, when of good quality, ı considerable quantity of ammonia, as well as phosphates, an(it costs about 13*l*. per ton; whilst inferior guano, poor in am- monia but rich in phosphate of lime, and superphosphate o lime containing no ammonia at all, sell for only from one-thir(to one-half as much.

* Of such manures, the Schedules of the Committee on Unexhausted Improve *ments* include particulars relating to Kainit, ashes, night-soil, and town manure *soot, sea-weed, fish*, and "*other* fertilisers unenumerated."

Nitrate of soda contains nitrogen as nitric acid; sulphate of ammonia contains it as ammonia; and Peruvian guano also contains, or by decomposition yields, it as ammonia. In fact, the money-value as manure, of nitrate of soda, or of sulphate of ammonia, is exclusively, and that of Peruvian guano chiefly, due to the nitrogen they contain.

Thus it will be seen that the highest-priced manures are those which are rich in nitrogen. A few illustrations may here be given of the effects of nitrogenous manures upon the growth of crops.

Barley has now been grown in one field at Rothamsted for 23 years in succession. On one portion there has been applied, every year, a mineral manure, consisting of salts of potass, soda, and magnesia, and superphosphate of lime; and the average produce over the 23 years has been 26¼ bushels of dressed corn per statute acre. On other portions there were used, every year, the same mineral manures, with the addition of ammonia-salts or nitrate of soda, and the average produce then reached very nearly 49 bushels per acre per annum; or nearly double that by the mineral manures used alone. Indeed, the produce obtained by using this mixture of mineral and nitrogenous manure was even rather higher than that yielded by the use, for 23 years in succession on the same land, of 14 tons of farmyard-manure per acre per annum.

In an immediately adjoining field wheat has been grown, without manure, and by different descriptions of manure, for 31 years in succession, and with very similar results. Mineral manures alone have given very little increase of produce; nitrogenous manures alone, in the form of ammonia-salts or nitrate of soda, have given considerably more produce than mineral manure alone; and the mixture of mineral and nitrogenous manures has yielded much more still, and more, of both corn and straw, than the annual application of farmyard-manure.

Thus, then, not only are those manures which are rich in nitrogen the highest priced, but direct experiments, extending over a long series of years, have shown that nitrogen has in reality a higher money-value for the purposes of manure than any of the other substances used.

It will be seen further on, how much the settlement of all questions of compensation for unexhausted manures must depend upon the estimate formed of the amount, and of the condition, of the nitrogen of the manure remaining in the soil; and how much this, in its turn, must depend on the description of the manure employed, the character of the soil to which it has been applied, the characters of the climate or of particular seasons, and the kinds of crop which have been grown since the application.

Unexhausted Manures.

When a manure is applied to the soil, what happens? This point may be illustrated very usefully for our present purpose by reference to direct results obtained at Rothamsted.

To certain plots given quantities of salts of potass, soda, and magnesia, superphosphate of lime, and salts of ammonia (or nitrate of soda), have been applied every year; and for between twenty and thirty years full crops of wheat and of barley have been obtained under this treatment.

Analysis of the produce has shown that a large proportion of the nitrogen supplied in the manure has remained unrecovered in the increase of the crop produced by its use. Still, any reduction in the quantity annually applied was followed by a diminution in the amount of the crop; or, if the application were entirely stopped, there was frequently little or no effect upon succeeding crops from any unexhausted residue.

Analysis of the soil showed that a portion of the nitrogen of the manure which was not recovered in the increase of crop was accumulated within the soil. But there yet remained a large amount of the supplied nitrogen to be otherwise accounted for than either in the crop or in the soil.

It was next determined that the drainage-water from the various plots of the experimental wheat-field, which was already pipe-drained, should be examined. Numerous samples of the drainage-water from the differently-manured plots, collected at different periods of the year, have, by their own desire, been supplied for analysis, independently, to Professor Voelcker and to Professor Frankland. Their analyses proved that the drainage-waters frequently contained a large amount of nitrogen in the form of nitrates; that the quantity of nitrates was the greater the greater the amount of ammonia-salts applied as manure; and that (after autumn-sowing) the quantity was very much greater in the winter, than subsequently in the spring and summer.

In one case, after a heavy dressing of ammonia-salts, Dr. Frankland found a quantity of nitrates in the drainage-water, which would correspond to a loss of nearly 18 lbs. of nitrogen per statute acre, provided an inch of rain had passed as drainage of that strength. On another occasion, after a heavy dressing of nitrate of soda, Dr. Voelcker found a quantity of nitrates in the drainage-water, which, reckoned in the same way, would be equivalent to a loss of about 13 lbs. of nitrogen per acre.

Lastly, on this point, calculation led to the conclusion, that *most probably* the whole of the nitrogen which had been sup-*plied as manure* in the ammonia-salts or nitrate of soda, and *which was not* either recovered in the increase of crop, or

retained by the soil in a very slowly available condition, was drained away and lost.

When the manure employed contains or yields ammonia, what happens is, that the ammonia becomes more or less rapidly oxidated in the soil, and so converted into nitric acid, which is washed away in the drainage-water, chiefly in combination with lime, or soda, or both, if not in the mean time taken up by a growing plant. When, however, nitrate of soda is applied, its great solubility, and the much less power of the soil for the absorption of it, or of its products of decomposition, than for that of ammonia, render it more liable still to loss by drainage if heavy rain should follow soon after sowing.

Although the *nitrogen* of manures is thus found to be very liable to loss by drainage, direct experiments show that the two important mineral constituents—*phosphoric acid* and *potass*—are much less liable to such loss.

Thus, Dr. Voelcker's analyses of the drainage-waters showed them to contain very little of either phosphoric acid or potass; and analyses of the soils themselves, made by Hermann von Liebig, son of the late Baron Liebig, showed that they contained considerably more of both phosphoric acid and potass—especially in the upper layers—the greater had been the supplies of them by manure. Experiments in the field further showed that these substances, though remaining dormant and ineffective in the soil in the absence of a sufficient supply of nitrogen, become effective even for twenty years or more, after their application, if nitrogen in an available form be also provided within the soil.

Of the three constituents of manures—*nitrogen*, *phosphoric acid*, and *potass*—which, in the sense that by the production and sale of corn and meat they are the most likely to become relatively deficient, are the most important constituents of manures generally, it is then proved, that the *nitrogen* is, at any rate when applied to ammonia-salts or nitrate of soda, very liable to loss by drainage, whilst the phosphoric acid and potass are, in a much greater degree, retained by the soil.

When farmyard-manure is employed, or other manures containing a large quantity of nitrogenous organic matter are used, the result is not quite so simple. For example, in farmyard-manure a portion of the nitrogen exists as ready-formed ammonia, but a large proportion becomes only very gradually converted into ammonia as the nitrogenous organic matter decomposes in the soil. Indeed, owing to the slow decomposition of dung, and the tardiness with which a large proportion of its nitrogen becomes available for the use of the growing crop, *three or four times* more nitrogen in the form *of dung, than in active artificial* manures, must be applied

to produce the same effect upon the immediately succeeding crop.

How slow is the perfect decomposition of dung in the soil, and how slowly a large proportion of its nitrogen becomes available for the use of growing crops, is strikingly illustrated in the following facts:

In the experiments at Rothamsted on permanent grass-land, one plot received 14 tons of farmyard-manure per acre per annum, for 8 years, 1856-'63, and gave an average produce of 43 cwts. of hay, against 23¾ cwts. on the unmanured plot over the same period. During the subsequent 11 years, 1864-'74, there has been no further application of dung or of any other manure on the previously dunged plot, and the average produce over the 11 years has been 33½ cwts. of hay, against 19½ over the same period on the plot unmanured from the commencement. The total *increase* during the 8 years of the application of the dung was 7 tons 12½ cwts. of hay; and the total *increase* during the next 11 years, due to the residue of the dung previously applied, was 7 tons 13½ cwts.; but it has fallen off very much during the later years, averaging considerably less than one-half as much over the last 5, as over the first 6 of the 11 years. It is probable that, during the whole 19 years, not more than two-thirds as much nitrogen has been removed in the total produce of hay as was supplied in the manure, and the increase of nitrogen over that contained in the permanently unmanured produce has probably been not one-fourth as much as was supplied.

Again, for twenty years in succession, 14 tons of dung were applied per acre on one plot in the experimental barley-field. Calculation showed that a much smaller proportion of the nitrogen of the dung was taken up by the increase of crop, than of that supplied in ammonia-salts or nitrate of soda; and, judging from other experiments, it is concluded that the percentage of nitrogen in the surface-soil has been increased by the residue of the dung to nearly double that of any other plot in the field. Yet when, after twenty years, the application of dung was stopped on one-half of the plot, and continued on the other half, the average produce over the next three years was, without further application, 44 bushels of dressed corn, and 2684 lbs. of straw; but where the application was continued, it was, over the same three years, 52½ bushels of dressed corn, and 3502 lbs. of straw; or there was an average per acre per annum of 8½ bushels more of dressed corn, and 818 lbs. more straw, where the dung was applied afresh, than where the application had been discontinued. It is true that the produce without further application was large, and no doubt largely due to the residue from the previous applications of dung; but, notwithstanding the very great accumulation within the soil of nitrogen, and,

doubtless, of all other constituents also, the produce did not reach the maximum which the characters of the seasons admitted of, but was considerably exceeded on the fresh application of dung.

Dung, however, possesses two very important properties—one mechanical and the other chemical. By reason of its bulk, and the quantity of organic matter it contains, it serves to render the soil more open and porous, and so to enable it not only to retain more water in a favourable condition, but also to absorb and retain more of the valuable constituents of the manure, and so to arrest the passage of them in solution into the drains. Further, by the gradual decomposition of the organic matter of the dung, the pores of the soil become filled with carbonic acid, which probably serves to retard the oxidation of the ammonia into the more soluble form of nitric acid, in which it would be more liable to be washed out and lost by drainage. From these facts it will be readily understood how it is that dung is more lasting in its effects than the more active artificial manures.

Still, in the experiments at Rothamsted in which dung has been applied year after year for many years in succession, there is a large amount of the nitrogen so supplied which is not yet accounted for either in the increase of crop or in the soil. Whether there is an ultimate loss of a greater or a less proportion of that supplied than when ammonia-salts or nitrate of soda is used; whether the loss will be proportionally the same when dung is used in more moderate quantity; or whether the loss be wholly, or chiefly, by drainage, or in other ways, the evidence at present at command is not sufficient to determine with certainty.

From the foregoing observations on the characteristics of some of the most important descriptions of manure, it will be obvious how essential it is to take into careful consideration the peculiar properties, and probable duration of effect, of different manures, if we would hope to arrive at anything like a fair estimate of the money-value of the unexhausted residue they leave in the soil under various circumstances.

Guided by such knowledge as I possess on the various essential points of the question, I will now endeavour to estimate the value of the unexhausted residue of various manures, under the circumstances in which that value is most likely to become the subject of claim for compensation. In all cases, the valuation is expressed in the number of shillings estimated to be due to the outgoing tenant, for twenty shillings original *manure-value.* The valuations given must, however, be taken as only approximately correct, as the amounts due might be affected very materially—according to the cleanliness or foulness of the land, the lightness or heaviness of the soil, the dryness or wetness of the locality or of particular seasons, and the difference be-

tween the purchasing price of the food or manure and its actual and relative value.

1. Manure from Purchased (or Saleable) Feeding-stuffs.

Claims for compensation for unexhausted manures will probably arise more frequently under this head than under any other. It will be necessary, therefore, to consider the question in some detail.

When the farmer uses purchased feeding-stuffs, or food the produce of the farm which he would otherwise be justified in selling, he looks for his remuneration partly to the increased value of his animals, and partly to the value of the manure obtained from them. The increased value of the animals is of itself seldom, if ever, equal to the cost of the food consumed. Unless, therefore, the outgoing tenant can rely upon obtaining compensation for the value of the manure produced from such food, he must either cease to purchase it, and feed his animals on the non-saleable produce of the farm alone for a year or two before he leaves it, or he must submit to a loss which sometimes will be very considerable.

Before we can approach the question of the value of the *unexhausted residue* of manure produced by the consumption of purchased (or saleable) food-stuffs, it is necessary to come to some decision as to the original value of such manure. In other words, we must endeavour to determine how much of the cost of any particular food should be charged to the manure account.

With regard to the value of different foods for feeding purposes, it may be stated in general terms, as the conclusion drawn from hundreds of feeding experiments with different descriptions of food made at Rothamsted, that, weight for weight, there is very much less difference in the *feeding-value* than in the *manure-value* of foods which are included in what may be called the same class. For instance, it will make comparatively little difference, so far as the increase in live-weight of the animal is concerned, whether a ton of cake, a ton of pulse, a ton of Indian meal, or a ton of barley, be given to fattening oxen or sheep, and comparatively little whether a ton of clover-hay or a ton of meadow-hay be used. Within each of these classes of food, however, there would be a much wider difference in the value of the manure which the consumption of a ton of each of them would produce.

Having regard to the results of the feeding-experiments above referred to, and taking into consideration the known average composition of different descriptions of food, an estimate was *made of what proportion* of certain of the constituents in a ton of *various foods would*, on the average, be stored up in the animal

itself, and what proportion would be obtained in the manure produced. The value, for manure, of those constituents was then calculated, and the results are given in Table I., below, the substance of which I first published about fifteen years ago. Those estimates of *manure-value* were, at the time, considered by some to be somewhat too high. They have lately been carefully reconsidered; and taking into account the higher money-value of some of the constituents at the present time, it has been decided to make but little further alteration than to add a few articles to the list that were not originally included in it.

TABLE I.—ESTIMATED VALUE of the MANURE obtained by the CONSUMPTION of different ARTICLES of FOOD, each supposed to be good quality of its kind.

No.	DESCRIPTION OF FOOD.	Money-value of the Manure from one Ton of each Food. £	s.	d.
1	Cotton seed-cake, decorticated	6	10	0
2	Rape-cake	4	18	6
3	Linseed-cake	4	12	6
4	Cotton seed-cake, not decorticated	3	18	6
5	Lentils	3	17	0
6	Beans	3	14	0
7	Tares	3	13	6
8	Linseed	3	13	0
9	Peas	3	2	6
10	Indian meal	1	11	0
11	Locust-beans	1	2	6
12	Malt-dust	4	5	6
13	Bran	2	18	0
14	Coarse pollard	2	18	0
15	Fine pollard	2	17	0
16	Oats	1	15	0
17	Wheat	1	13	0
18	Malt	1	11	6
19	Barley	1	10	0
20	Clover-hay	2	5	6
21	Meadow-hay	1	10	6
22	Bean-straw	1	0	6
23	Pea-straw	0	18	9
24	Oat-straw	0	13	6
25	Wheat-straw	0	12	6
26	Barley-straw	0	10	9
27	Potatoes..	0	7	0
28	Parsnips...	0	5	6
29	Mangold wurtzel	0	5	3
30	Swedish turnips	0	4	3
31	Common turnips	0	4	0
32	Carrots	0	4	0

The prices given in the foregoing Table represent what it will be convenient to term the *manure-value* of a ton of the different descriptions of food; that is to say, the value of the manure provided it reached the soil without material loss, and was not subject to loss by drainage before the growth of a crop. These prices might conveniently be taken as a basis in the settlement of claims for compensation for the unexhausted residue of manure derived from the consumption of purchased or saleable feeding-stuffs, provided the system of valuation now under consideration were adopted.

Anyone acquainted with the cost and the feeding-value of the different foods will see, by a glance at the Table, how little connection there is between either the cost, or the feeding-value, of a ton of the different foods, and what may be termed their *manure-value.*

It is clear, therefore, that it would be quite fallacious to base a claim for compensation for the unexhausted manure from purchased food, either upon the number of tons of food consumed, regardless of the description of that food, or upon the amount of money expended in its purchase. For example, the cost of a ton of undecorticated cotton-cake, and of a ton of locust-beans, would be much about the same; but the Table shows that the estimated value of the manure from the consumption of a ton of the cotton-cake would be 3*l.* 18*s.* 6*d.*, whilst that from a ton of locust-beans would be only 1*l.* 2*s.* 6*d.* Hence, the same outlay—according as a ton of the one or of the other of these two descriptions of food were purchased—would result in a difference of 2*l.* 16*s.* in the value of the manure thereby brought upon the farm.

The *manure-value* alone should, therefore, be adopted as the basis of any calculations of the value of the unexhausted residue of manures derived from the consumption of purchased or saleable food-stuffs.

Adopting the *manure-value* of the different foods, as given in the Table, I will now endeavour to estimate, to the best of my ability, the value of the unexhausted residue of such manure, under various circumstances which are likely to occur.

When the ordinary manure of the farm is enriched by the consumption of purchased or saleable foods, the first crop grown after the application of such manure will be considerably increased. The second and third crops will, according to circumstances, be more or less benefited; but, practically speaking, there will be no unexhausted residue left at the end of the rotation.

If purchased food be consumed with a root-crop by the outgoing tenant, and he take no crop grown by the manure so produced, *he should be allowed* compensation at the rate of 17*s.* for every

20*s.* of the original *manure-value* of the food if it have been consumed on the land, or 16*s.* if consumed in the yards. If he take one corn-crop produced by such manure, sell the corn, but leave the straw on the farm, he should be allowed 7*s.* for every 20*s.* of the original *manure-value* of the purchased or saleable food. If he have taken a second corn-crop, leaving the straw, he should be allowed 1*s.*; or if, instead of a second corn-crop, grass or hay be grown and consumed on the farm, 2*s.*; but if the second crop after the roots be hay which he has sold, nothing should be awarded to him.

If purchased or saleable food be consumed on grass-land, and the outgoing tenant have not afterwards removed a crop of hay, he should be allowed 18*s.* for 20*s.* original *manure-value* of the food. If he have taken one crop of hay, and consumed it on the farm, he should be awarded 11*s.*; but if the hay have been sold, only 2*s.* for 20*s.* of the *manure-value* of the food. After a second year's hay-crop, if consumed, 2*s.*; but if sold, nothing should be allowed. If the land be only pastured, and purchased food be consumed on it for one, two, or three years before leaving, the compensation might fairly be fixed at 18*s.* for 20*s.* original *manure-value* after one year, at 12*s.* after two years, and at 4*s.* after three years.

2. Farmyard or Town-stable Manure.

Farmyard-manure, made from the produce of the farm, should not be made the subject of any claim for compensation by the outgoing tenant, whether such manure have grown a crop, or remain in the yards, or on the land, unless he paid for it under the same conditions on entry. The cases of the enrichment of such manure by the use of purchased (or saleable) cattle-food would be taken into account under the provisions of the previous sub-section (1).

When stable-manure is purchased and used in large quantities, and the application has extended over a long series of years, as, for instance, in the case of garden-ground, the unexhausted residue remaining in the soil is very great, and large crops may be taken from such land, without further manuring, for a number of years in succession. Such cases would require special consideration and adjudication, if not provided for by special agreement, as would generally be the case.

When purchased stable-manure is only used in the moderate quantity usual in ordinary agriculture, and only once in the course of a rotation of four or five years, it may be assumed that towards the end of such period no unexhausted residue would remain which would be sufficient to justify a claim for compensation to the outgoing tenant.

If purchased stable-manure be applied for roots which are consumed on the land, 17*s.* for every 20*s.* of the original value of the manure may be allowed; but if the roots be consumed in the yards, only 16*s.* If one corn-crop be afterwards taken, the corn sold, but the straw left on the farm, 9*s.* may be allowed; if a second crop have been taken, the corn sold, but the straw left, 3*s.* should be allowed; or if, instead of a second corn-crop, grass or hay be grown and consumed one year, 5*s.*; but if the hay be sold, or the grass have been grazed a second year, only 2*s.* should be allowed.

If such manure be applied directly for a corn-crop, the corn sold, and the straw left, 12*s.* for 20*s.* of the original value of the manure may be awarded. After a second corn-crop, 6*s.*; or if, instead of a second corn-crop, grass or hay be grown and consumed one year, 8*s.*; or if the first year's hay be sold, or the produce grazed or consumed a second year, only 4*s.* should be allowed.

If the manure be applied directly to grass-land, and the produce is entirely grazed, 18*s.* may be allowed after one year, 14*s.* after two years, 8*s.* after three years, and 2*s.* after four years. If the manure be applied to grass-land, and hay be taken exclusively for consumption on the farm, the allowance should be 16*s.* after one year, 12*s.* after two years, and 6*s.* after three years; or if the hay be sold, 10*s.* after one year, 4*s.* after two years, but nothing after three years should be allowed.

3. Rape-cake (or other Cake) used as Manure.

When rape-cake, or other cake, is used as manure, a considerable portion of it decomposes pretty rapidly in the soil, and the more so the lighter and more porous the soil. It yields up a much larger proportion of its nitrogen, and other manurial constituents, in the first year of its application, than does farmyard-manure; and accordingly, in practice, a quantity not containing one-fourth the amount of nitrogen of an ordinary dressing of dung would be applied to produce the same effect on the first crop. An ordinary dressing of rape-cake, therefore, after the first crop, leaves a very much less unexhausted residue than an ordinary dressing of dung. A given quantity of nitrogen applied as rape-cake would, on the other hand, be less rapidly available and effective than the same quantity applied as nitrate of soda, sulphate of ammonia, or Peruvian guano; but it would be less liable to loss by drainage, and would, therefore, leave a larger proportion as unexhausted residue after the first crop, than either of the above-named more rapidly active manures.

If the outgoing tenant have applied cake as manure for a root-

crop, and the roots have been consumed on the farm, he should receive compensation at the rate of 16*s.* for 20*s.* cost of the manure if they were consumed on the land, and of 15*s.* if consumed in the yards. If a corn-crop have been grown after the roots, the corn sold, and the straw left, he might receive 7*s.* for 20*s.* cost of the manure; if a second corn-crop, 1*s.*; or if, instead of a second corn-crop, grass or hay be grown and consumed, 3*s.*; but if hay be sold, nothing should be allowed.

If the cake be applied directly for a corn-crop, the corn sold, and the straw left, 7*s.* for 20*s.* cost of the manure may be allowed. If a second corn-crop have been taken, 1*s.*; but if a third, nothing should be allowed. If, instead of a second corn-crop, grass or hay be grown and consumed, after one year, 3*s.*, or after two years, 1*s.*; but if hay be sold, nothing should be awarded.

4. Bones.

Ordinary crushed or half-inch bones decompose less rapidly, and are, therefore, less rapidly active, than finely-ground bones. In either state bones are less rapidly active than rape-cake, and, like rape-cake, are much less so than nitrate of soda, ammonia-salts, or guano. The action of bones depends, moreover, very much upon the characters of the soil to which they are applied. In heavy soils their action is very slow, and therefore the more lasting; but in light soils it is more rapid, and less lasting.

In the case of soils to which experience has shown that bones can be applied with effect and profit for the root-crop, if so applied, and no crop have been grown from the manure produced by the consumption of the roots, the allowance might be 17*s.* for 20*s.* original value, if the roots have been consumed on the land, or 16*s.* if consumed in the yards. If a corn-crop have been taken after the roots, the corn sold, and the straw left, 8*s.*; if a second corn-crop, 2*s.*; if, instead of a second corn-crop, grass or hay be grown and consumed one year, 4*s.*; or if hay be sold, or grass or hay consumed a second year, only 1*s.* should be allowed.

If bones be applied to suitable grass-land, which is entirely grazed, 18*s.* for 20*s.* original value may be allowed after the first year, 13*s.* after the second, 6*s.* after the third, and 1*s.* after the fourth year. If the grass be made into hay and consumed on the farm, 16*s.* after one year, 10*s.* after two years, and 3*s.* after three years, may be allowed. If the hay be sold, 10*s.* may be allowed after the first year, 4*s.* after the second, but nothing after the third year.

5. Nitrate of Soda.

From what has been already said of the loss of the nitrogen of manure by drainage, and especially of the very great loss that may arise when such soluble and rapidly active nitrogenous manures as nitrate of soda or ammonia-salts are used, it will be readily understood that, when they are employed, we have not to look forward very far to reach the limit of their action, and consequently the period at which any claim for compensation for their unexhausted residue should cease. This point is in fact sooner reached in their case than in that of any other nitrogenous manures. Next in order in lasting character, so far as the nitrogen is concerned, comes guano, then perhaps, folding, then rape-cake, and then bones; whilst farmyard-manure is the most lasting of all.

Notwithstanding the very great solubility of nitrate of soda, and its greater liability to loss by drainage than any other nitrogenous manure, some experiments at Rothamsted have shown that after it had been used in large quantities, and for many years in succession, considerable benefit accrued to future crops. To what extent this result was due to the disintegration of the subsoil, by which it became more porous, more capable of retaining water in a condition favourable for the growing crop, and more permeable to its roots, and how much to the retention of nitric acid by virtue of the increased porosity, and therefore increased surface for absorption, of the subsoil, there is not sufficient evidence to show. It would, indeed, be quite unsafe to assume that any conclusions applicable to ordinary practice can be drawn from these results, obtained under such exceptional circumstances.

It must in fact, for practical purposes, be assumed that nitrate of soda, used only occasionally, and only in the moderate quantities usually applied, leaves no beneficial residue after the removal of the first crop. Whatever is not taken up by the crop itself, or washed out during its growth, will probably be in great part drained away in the winter following, leaving at any rate but a small, an uncertain, and a doubtfully effective residue.

If nitrate of soda have been used for roots consumed upon the farm, and the manure so produced have not yielded a crop, 15*s.* for 20*s.* original value of the manure may be allowed if the roots have been consumed on the land, or 14*s.* if in the yards. If the manure produced from the consumption of the roots have yielded a corn-crop, the corn sold and the straw left, 4*s.* for 20*s.*; or if a second corn-crop have been taken, 1*s.*; or if instead of a second corn-crop, grass or hay be grown and consumed, 2*s.* may be allowed.

When nitrate of soda is applied for a corn-crop, the grain sold by the outgoing tenant, and the straw left on the farm, he should receive 6*s*. for 20*s*. cost of the manure; nothing after a second corn-crop; but if, instead of a second corn-crop, grass or hay be grown and consumed, 1*s*.

If nitrate of soda have been applied to grass which has been only pastured, 16*s*. for 20*s*. of original value of the manure should be allowed after one year, 10*s*. after two years, and 2*s*. after three years; if hay have been taken and consumed, 14*s*. after the first year, 8*s*. after the second year, and 1*s*. after the third year; but if the hay have been sold, 2*s*. after one year, but nothing afterwards should be allowed.

6. Sulphate of Ammonia.

The only salt of ammonia used to any extent for agricultural purposes is the sulphate of ammonia. As already said, this is used to a considerable extent, but chiefly in the manufacture of mixed manures. When sown in the autumn it will be more liable to loss by drainage than when sown in the spring; but when sown in the spring, it will probably be less liable to loss by drainage than nitrate of soda sown at the same time. It is more liable to such loss in the case of light and porous soils and subsoils, than of soils and subsoils of more retentive character.

The same rules for compensation will be applicable to sulphate of ammonia as to nitrate of soda, provided the circumstances of its application, as above referred to, be the same.

7. Superphosphate of Lime made from Mineral Phosphates.

It has been explained that the phosphoric acid and the potass of manures are comparatively little liable to loss by drainage, at any rate when applied to the heavier soils. In fact, superphosphate leaves a considerable unexhausted residue; but that residue is, as a rule, without appreciable effect on succeeding crops, unless nitrogenous manure be applied to take it out. If, therefore, the crop for which the manure has been applied has been wholly sold by the outgoing tenant, no residue will remain to which a money-value can be assigned.

The most prominent effect of superphosphate of lime when applied to a root-crop is to cause a great development of root-fibres, thus enabling the plant to gather up much more of other food from the soil. It therefore serves to increase the immediate effect of other manures supplied with it; also to turn to

account accumulations within the soil which, if not taken up, would be liable to loss by drainage.

When superphosphate has been applied to roots, and no crop has been taken from the manure produced by their consumption, 9*s.* for 20*s.* of its cost may be allowed if the roots be consumed on the land, or 8*s.* if in the yards; or if corn have followed the roots, the grain sold and the straw left, 2*s.* may be allowed.

When superphosphate has been applied for a corn-crop, the corn sold and the straw left, compensation to the extent of 5*s.* for 20*s.* cost of the manure might be granted.

If superphosphate have been applied to grass-land which has been grazed, for every 20*s.* cost, 12*s.* after one year, 4*s.* after two, but nothing after three years should be allowed. If applied to grass-land, and hay have been taken and consumed, 10*s.* after one year, 2*s.* after two years, and nothing after three years. If hay have been sold, nothing should be claimed.

No compensation should be claimed for the unexhausted residue of superphosphate, whenever a second crop of any kind has been taken since the application, excepting corn after roots, grass grazed, or hay consumed, as above specified.

8. Guano, in its Natural State, or Manufactured.

Under the existing conditions of the Peruvian guano trade it is impossible to speak with any certainty, even as to the value of guano as a direct manure. It must therefore be more difficult still to speak definitely as to the value of the residue it may leave in the soil after the removal of a crop.

At one time the farmer could calculate upon receiving guano containing nitrogen equal to 16 per cent. of ammonia; more recently he had to be satisfied with 14 per cent.; and more recently still, not only a lower average per cent. than this, but great uncertainty whether he would receive that amount, half as much, or even less.

The present agents for the sale of Peruvian guano in this country have, however, quite recently informed me, that, during the time the agency has been in their hands, their importations have averaged nearer 13 than 12 per cent. of ammonia, and that cargoes analysing anything below 12 per cent. have been quite the exception. Such guano, in its natural state, will probably also contain from 25 to 30 per cent. of phosphates. But some they mix with sulphuric acid, and manufacture it into a substance of uniform quality containing nitrogen equal to about 10 per cent. of ammonia, superphosphate equal to about 20 per cent. of phosphate rendered soluble, and only about 4 per cent. *of phosphates* left undissolved.

Such a manufactured guano would rank in a position intermediate between the more highly or purely nitrogenous manures (such as nitrate of soda and sulphate of ammonia) on the one hand, and a superphosphate of lime on the other; or rather, it would be equivalent to a mixture of the two.

Other manure-dealers also prepare "dissolved guano," but of very varying composition.

From what has been said in regard to the action, and the value, of different descriptions of manure, it will be readily understood that the value of guano will depend very greatly upon the percentage of nitrogen it contains. The nitrogen in guano, whether "dissolved" or not, should be valued at the rate for the time of that in nitrate of soda, or sulphate of ammonia.

If the guano be "dissolved" by admixture with sulphuric acid, the value of the phosphates rendered soluble may be reckoned as the same as that in superphosphate of lime, but if not dissolved at only two-thirds as much.

Thus it will be obvious that the mere price paid for guano cannot be accepted as the basis upon which to calculate the value of its unexhausted residue after it has yielded a crop. It is essential for the establishment of a claim for compensation that the composition of the guano should be known, and its actual value calculated, according to the amount of ammonia it contains or yields, the amount and condition of its phosphates, the price of ammonia in sulphate of ammonia, and that of soluble phosphate in superphosphate.

If the guano have been acted upon by sulphuric acid, both its nitrogen and its phosphates will probably be more effective on the first crop, and leave, therefore, the less for succeeding crops, than if it were used in its natural state. But the difference would not be either sufficiently great, or sufficiently uniform on various soils and in various seasons, to justify a difference in the scale of valuation of the unexhausted residue.

If guano, whether dissolved or not, have been used for roots consumed upon the farm, and the manure so produced has not yielded a crop, 15*s.* for 20*s.* estimated value of the guano may be allowed if the roots be consumed on the land, or 14*s.* if in the yards. If the manure produced from the roots have yielded a corn-crop, the corn being sold and the straw left, 4*s.* for 20*s.* value of the guano should be allowed; if a second corn-crop have been taken, 1*s.*; or if, instead of a second corn-crop, grass or hay be grown and consumed, 2*s.*

If guano, whether dissolved or not, have been directly applied for a corn-crop, the grain sold, and the straw left, 6*s.* for 20*s.* value of the guano might be awarded. If after one corn-crop,

grass or hay be grown and consumed on the farm, 1*s.* may be allowed; but if a second corn-crop be taken, or hay be cut and sold, no claim for compensation should be admitted.

If guano be applied to grass-land, 16*s.* for 20*s.* estimated original value may be allowed after one year, 10*s.* after two years, and 2*s.* after three years, if the produce be only grazed; if it be made into hay which is consumed, 14*s.* after one year, 8*s.* after two years, and 1*s.* after three years; or if a crop of hay be taken and sold, only 2*s.* should be allowed.

9. Other Manures of more or less unknown Composition.

Under this head may be included—special grass-manures, corn-manures, root-manures, or other compound artificial manures; also dried blood, shoddy, Kainit, ashes, night-soil, soot, other town-manures, sea-weed, fish, and some other refuse-matters.

As in the case of guano, so in that of each of the above manures, the mere price paid for it cannot be accepted as the measure of its value. If any claim for compensation for the unexhausted residue of such manures is to be made, it is absolutely essential that the composition of the manure used should be known.

It is obviously requisite that any Act by which power is given to an outgoing tenant to claim compensation for unexhausted manures should give the person subject to such claim power to ascertain the composition and value of the manures in respect to which the claim is made. In all cases, therefore, in which it is intended to put in such a claim, the person making it should be required to give notice to the landlord that he is about to use certain manures, from which he may have samples taken for analysis if he desire it.

Professor Voelcker in England, the late Professor Anderson in Scotland, and Professor Cameron in Ireland, have from time to time drawn attention to the numerous frauds committed upon tenant-farmers by the sale of spurious manures; and if a purchaser do not take the trouble to protect himself from fraud when his own interest alone is concerned, he is little likely to do so if, by afterwards claiming compensation based upon the amount of his outlay, he can shift a portion of the loss upon some one else.

The value of a manure of this class will depend almost exclusively on the quantity, and the condition, of the nitrogen and of the phosphates, and in the case of Kainit of the potass, which it contains.

Special grass, corn, root, or other compound manures, will

sometimes contain their nitrogen as sulphate of ammonia, but frequently in the form of shoddy, or other nitrogenous organic matter. If the nitrogen exists as sulphate of ammonia it should be valued at the same rate as in that substance. The nitrogen in shoddy, and in most other nitrogenous organic matters used as manure, is, however, much more slowly effective than that in nitrate of soda, sulphate of ammonia, or guano. As a rule, therefore, the nitrogen of manures which exists as nitrogenous organic matter should be valued at only from one-half to two-thirds the price of that in nitrate of soda, sulphate of ammonia, or guano.

A given quantity of nitrogen in nitrogenous organic matter being less rapidly effective, and probably less liable to loss by drainage also, than that in nitrate of soda, sulphate of ammonia, or guano, will of course leave proportionally more for succeeding crops. The result will, however, be so dependent on the description of the organic matter employed, the kind of soil to which it is applied, the characters of the seasons, and other circumstances, and the residue itself would, in some cases, be so slowly available, that, practically speaking, the unexhausted residue from nitrogenous organic matter applied as manure cannot be taken at a higher value in proportion to the original value of the manure settled as above, than in the case of the more rapidly active nitrogenous manures.

The phosphate of manures of this class, if in the state of superphosphate, should be valued as in superphosphate.

The following scale of compensation for unexhausted residue might be adopted when any of these compound artificial manures are used.

When applied to grass, and the produce has been only grazed, 14*s.* for 20*s.* original value of the manure, calculated as above, may be allowed after the first season, 6*s.* after the second, but nothing after the third. If hay be taken and consumed on the farm, the allowance may be 13*s.* after the first year, and 4*s.* after the second year; but if the hay have been sold, only 2*s.* should be allowed.

When applied for a corn-crop, the corn being sold and the straw left, 6*s.* for 20*s.* estimated value of the manure should be allowed. If a second corn-crop be taken no allowance should be made; but if, instead of a second corn-crop, grass or hay be grown and consumed, 1*s.* may be allowed.

When applied for a root-crop, the roots consumed upon the farm, and the manure so produced have not yielded a crop, 12*s.* for 20*s.* of the value of the manure may be allowed if the roots be consumed on the land, or only 10*s.* if consumed in the yards. If a corn-crop has been *grown by* the manure of the consumed

roots, the grain sold, and the straw left on the farm, 2*s*. for 20*s*. of the estimated value of the manure should be allowed.

Special potass-manures, such as Kainit, are only profitable under such exceptional circumstances as to soil and cropping, that no special rule can be given for the valuation of the unexhausted residue from their use; and before any claim could be admitted, evidence of their utility on the farm in question should be required. When such utility is proved, the same proportion of the original market-value, founded on composition, might be allowed, under the same circumstances as to cropping, &c., as in the case of a mineral superphosphate.

In the case of any compound or refuse artificial manure, containing very little nitrogen, but a fair amount of soluble phosphates, the same proportion of the estimated value of the manure may be allowed for unexhausted residue as if it were a superphosphate. But if it contain very little of either nitrogen or soluble phosphates, no allowance whatever should be made for its use; excepting in the case of a potass-manure under the conditions above defined.

The foregoing remarks as to the circumstances to be taken into consideration in valuing the unexhausted residue of the various compound or refuse artificial manures of more or less unknown or uncertain composition, and the scales of compensation which have been suggested, will, it is hoped, serve as some guide to those who may have to adjudicate on claims made in relation to such manures. At the same time, it will be obvious that, owing to the great difference in the composition and value of such manures, no absolute rules can be laid down for the estimation of the value of any residue they may leave in the soil.

10. Liming, Chalking, Marling, &c.

Liming, chalking, and marling, are practices so far from being generally required, or generally adopted, in agriculture, and their cost and value are so dependent on local circumstances, that no general rules can be laid down for the valuation of their unexhausted effects. Still, where beneficially adopted, they would undoubtedly be fair subjects for compensation if the benefits were not unexhausted at the time of the tenant quitting his holding. If disputed, any claim should be settled upon the evidence, or might appropriately be submitted to the arbitration, of intelligent and disinterested persons of local practical experience.

Such, then, are the results of an attempt, very carefully made, *to construct* a scale of valuation of the unexhausted residue of

previously-applied manures which have already yielded a crop. It will be observed that a fundamental principle of the valuation is to take as the original value of the manure *not* its *cost-price*, but its properly ascertained *manure-value*. Further, the description of the crop or crops grown since the application of the manure, and whether the produce has been consumed or sold, have carefully been taken into account. But even supposing the estimates arrived at should be admitted or found to be in application as fair as, or fairer than, others in the majority of cases, it is freely granted that they might require very considerable modification, according to the cleanliness or foulness of the land, the lightness or heaviness of the soil, the dryness or wetness of the locality or of the particular seasons, and other circumstances. It is further granted that existing knowledge would not justify an attempt to take these essentially fluctuating conditions into numerical calculation, and to frame a sliding scale of allowances accordingly. Indeed, whatever basis or scale of valuation may be accepted as upon the whole the best, considerable latitude in its application must be allowed to those who may have the responsibility of making the award in individual cases.

The results of the valuation of the unexhausted residue of manures founded on their original *manure-value*, which have been considered in detail in the foregoing pages, are, for the convenience of easy reference and comparison, brought together in one view in Table II. overleaf.

TABLE II.

Estimated Money-Value of the **Unexhausted Residue** of **Manures** remaining after the Growth of different Crops, expressed in Shillings for every Twenty Shillings original *Manure-Value* of the Purchased Feeding-Stuff or Manure employed.

After		Purchased or Saleable Food.	Farmyard, or Town-stable Manure.	Rape-cake, or other Cake used as Manure.	Bones.	Nitrate of Soda.	Sulphate of Ammonia.	Guano, in Natural State, or Manufactured.	Compound Artificial, or Refuse Manures.	Super-phosphate, made from Mineral Phosphates.
	Purchased (or saleable) Feeding-Stuff consumed with Roots, or Manure applied for Roots.									
		Shillings allowable for every 20 Shillings original *Manure-value.*								
1st year	Food consumed with roots on land	17	..	..	..	..	..	..	..	..
1st year	Food consumed with roots in yards	16	..	..	..	..	..	..	..	..
1st year	Manure applied to roots consumed on land	..	17	16	17	15	15	15	13	9
1st year	Manure applied to roots consumed in yards	..	16	15	16	14	14	14	10	8
2nd year	Corn crop; grain sold, straw left	7	9	7	6	4	4	4	3	2
3rd year	Corn crop; grain sold, straw left	1	3	1	2	1	1	1	0	0
3rd year	Grass or hay consumed	2	5	3	4	2	2	2	0	0
4th year	Grass or hay consumed	0	2	0	1	0	0	0	0	0

Manure applied for a Corn-crop.

1st year	Corn crop; grain sold, straw left	..	12	7	..	6	6	6	6	5
2nd year	Corn crop; grain sold, straw left	..	6	1	..	0	0	0	0	0
2nd year	Grass or hay consumed	..	8	3	..	1	1	1	1	0
3rd year	Grass or hay consumed	..	4	1	..	0	0	0	0	0
2nd year	Hay sold	..	4	0	..	0	0	0	0	0

Feeding-Stuff consumed on, or Manure applied to, Grass-land—Grazed.

1st year	Grazed	18	18	..	18	16	16	16	14	12
2nd year	Grazed	12	14	..	13	10	10	10	6	4
3rd year	Grazed	4	8	..	6	2	2	2	0	0
4th year	Grazed	0	2	..	1	0	0	0	0	0

Feeding-Stuff consumed on, or Manure applied to, Grass-land—Hay consumed.

	No crop	18	..	..	..	..	..	..	..	..
1st year	Hay consumed	11	16	..	16	14	14	14	13	10
2nd year	Hay consumed	2	12	..	10	8	8	8	4	2
3rd year	Hay consumed	0	6	..	3	1	1	1	0	0
4th year	Hay consumed	0	0	..	0	0	0	0	0	0

Feeding-Stuff consumed on, or Manure applied to, Grass-land—Hay sold.

	No crop	18	..	..	..	..	..	..	..	..
1st year	Hay sold	2	10	..	10	2	2	2	2	0
2nd year	Hay sold	0	4	..	4	0	0	0	0	0
3rd year	Hay sold	0	0	..	0	0	0	0	0	0

SECTION II.—*Allowances according to the Established Custom oj different Counties and Districts.*

The Committee on "Unexhausted Improvements" appointec by the Council of the "Central and Associated Chambers o Agriculture" have sought to collect, and put on record, th particulars of the allowances recognised in different counties anc districts for a great variety of feeding-stuffs and manures. Theii schedules are arranged for returns relating to linseed-cake cotton-cake, other purchased feeding-stuffs, guano, nitrate o soda, sulphate of ammonia, nitro-phosphate or blood-manure special concentrated manures, bone-dust, superphosphate o lime, Kainit, ashes, night-soil, town-manure, rape-cake, soot sea-weed, fish, and "other fertilisers unenumerated." In thei Report, dated June 2, 1874, they state that they have receivec returns from 55 districts; extending from the most northern to the most southern, and from the most eastern to the mos western limits of England. The allowances vary accordingly a the purchased food is consumed in the yards or buildings, o pasture land, or on arable land; or accordingly as the manure i applied to root or green-crops consumed on the farm, to corn crops, the straw being left for consumption, hay-crops consumec on the farm, or to pasture; and accordingly, also, as the food o manure was employed in the last year, or the last year but one of the tenancy.

In all cases the allowance is expressed as a certain *proportion of the "original value"* of the purchased feeding-stuff o manure; "original value" meaning, it would appear, origina *cost* of the article.

It is understood that in some of the most important of th agricultural districts to which the returns refer, the scale of com pensation has been settled by the mutual consent of outgoin and incoming tenants; and some of the advocates of compul sory compensation seem anxious that certain of the customs i question should be extended to all parts of England. It seem very desirable, therefore, that the basis of a few of the most im portant of the recognised allowances should be carefully con sidered, and their results compared with those arrived at b other methods of valuation.

In the most important districts in which such customs are i force, and which are supposed to supply the best examples fo application to other localities, it so happens that there exists very rigid, or scarcely varying, rotation of crops, and that littl else than one or two standard feeding-stuffs, and one or tw standard manures, are used. Supposing, therefore, the basis c the allowances prevailing in those districts were to be adopte

for the country at large, the list, and the conditions, would have to be greatly enlarged if the requirements of the farming under the great variety of rotations, and with the great variety of foods and manures employed, in other districts, are to be provided for.

Of the returns in question, Schedule 1, Form B, apparently in an incomplete state, is the only one I have been able to obtain. From it I find that in Lincolnshire, and in some other districts, the allowance for purchased feeding-stuffs is one-half the original value of the quantity consumed by the outgoing tenant during the last year of his occupancy, a condition being that that quantity be not excessive; and it is the same whether the food have been consumed in the yards, on pasture, or on arable land.

The following Table shows, in parallel columns, the present price per ton of some staple feeding-stuffs, and the allowance to the outgoing tenant for its consumption, according to the customs referred to, founded on "original value" or cost. By the side of these is also shown the allowance that would be made according to the scale of valuation laid down in the foregoing Section (L); in the construction of which the original *manure-value* of the feeding-stuff after consumption, as given in the Table at page 13, is adopted as the basis, and it is assumed that the quantity of the feeding-stuff accepted as the year's consumption is the average amount of two, three, or more years, as the case may be, and the allowance is made on a declining scale from year to year, according to the crop grown, &c., as already fully explained.

	One Ton of Food Consumed per Annum.			
	"Original value" or Purchasing Price.	Allowance according to Lincolnshire Custom; half One Year's Consumption.	Allowance according to Manure-value; on Three Years' Consumption.	Allowance by "Custom" more (+), or less (−), than by "Manure-value."
	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*
Cotton-cake, decorticated ..	10 10 0	5 5 0	8 5 9	− 3 0 9
Linseed cake ..	12 10 0	6 5 0	5 17 11	+ 0 7 1
Wheat	9 10 0	4 15 0	2 2 1	+ 2 12 11

Although, according to the Lincolnshire custom, the allowance is half the original value of the last, or one year's consumption only, it is a condition that the quantity claimed upon shall only be a fair average of the consumption of three years; *so that, in point of fact,* the allowance, though only part of one

year's consumption, is, as in the case of my own scale, arranged to compensate for more than the consumption of the last year alone. In the case of my own scale, 17*s.* is allowed for every 20*s.* of original "*manure-value*" of the food if consumed on the land during the last year, and 16*s.* if consumed in the yards; and, in the example given in the Table, it is supposed that half is consumed on the land, and half in the yards; 7*s.* in 20*s.* is allowed for the amount consumed with roots in the last year but one, followed by a corn-crop; and 2*s.* for the amount consumed in the last year but two, followed by corn, and this by grass or hay consumed.

Of all purchased feeding-stuffs, linseed-cake is the one in the use of which farmers have the greatest experience, and the feeding and manure-value of which are therefore the best understood. It will be seen that the allowance for it is, according to the Lincolnshire custom, nearly the same as according to my more elaborate scale; and the agreement would be nearer still, if it were not that the cost of the cake is taken at the present exceptionally high price.

It is, however, when we come to other purchased feeding-stuffs, the feeding and manure-value of which is less understood, but in respect to which the allowance for compensation is, like that for linseed-cake, also based upon *original cost*, that we find very wide differences between the allowance according to the "customs," and according to *manure-value.* Thus, in the case of decorticated cotton-cake, which has not only the highest manure-value of any of the articles enumerated in the Table at page 13, but has also a very high manure-value in proportion to the purchasing price of the food, my estimate of unexhausted residue, founded on manure-value, is very much higher than that which would be allowed by the Lincolnshire custom. In the case of wheat, on the other hand, which has a very low manure-value, both actually and relatively to purchasing price, the allowance founded on *manure-value* would be considerably less than half that according to the Lincolnshire custom, founded on *original cost.*

These few examples are sufficient to show how entirely fallacious it is to assume that the manure-value of a food, whatever may be its composition, bears a fixed proportion to its original cost. It may, perhaps, be answered that my own estimates are erroneous; and certainly I do not intend to claim for them infallibility, but only that they are carefully made, with due regard to such knowledge as at present exists bearing upon the subject.

But let us test the question in another way. Wheat is much used for feeding at the present time, and the purchasing price of feeding qualities may be taken at 9*l.* 10*s.* per ton. On the assumption that the manure-value of any feeding-stuff is one-half

its purchasing price, that of a ton of wheat after consumption would be 4*l.* 15*s.* Now, the manure-value of consumed food may be said to depend almost exclusively on the amount of nitrogen, phosphoric acid, and potass, contributed to the manure; and the quantity of these constituents yielded by the consumption of a ton of wheat would be, in round numbers:—

	lbs.
Nitrogen..	34
Phosphoric acid, reckoned as phosphate of lime..	40
Potass	11

These manurial constituents could be purchased at the present time as follows:—

	£	*s.*	*d.*
34 lbs. nitrogen, in 220 lbs. nitrate of soda, at 14*s.* per cwt...	1	7	6
40 lbs. phosphate of lime (soluble), in 154 lbs. superphosphate, at 5*s.* 6*d.* per cwt.	0	7	6
11 lbs. potass in 22 lbs. sulphate of potass, at 16*s.* per cwt. ..	0	3	2
	£1	18	2

Thus, then, if wheat had been consumed, and compensation were allowed at the rate of one-half the original cost of the year's consumption, the incoming tenant would have to pay nearly 3*l.* more for each ton of wheat so used by his predecessor than the constituents he received in the manure could be purchased for in artificial manures. Not only so, the animal-manure would be subject to an unknown loss by winter rains, and would be less rapidly active than the same constituents applied in artificial manures in the spring.

Further, the allowances according to "Custom" vary very much in different localities, and even in closely-contiguous districts. Thus, within the limits of the West Riding of Yorkshire, in one district the allowance on the last year's consumption is one-half or one-third of the original value of the food, according to the description of the cake, or the conditions under which it has been consumed; and, for the last year but one, one-fourth the original value in all cases. In another district the allowance is, for the last year one-fourth, and for the last year but one one-eighth, under all conditions. In a third, it is for the last year one-third, and for the last year but one, nothing.

In South Staffordshire the allowance for linseed or cotton-cake consumed is, for the quantity used during the last year of the tenancy, two-thirds, and for that used during the last year but one, one-third, of the original value of the food. Supposing the outgoing tenant consumed 1 ton of linseed-cake annually upon his turnip-crop, followed by barley, he would receive compensation, according to the custom of South Staffordshire, founded on original value or *cost*, and according to my estimates, founded on *manure-value, respectively,* as follows:—

According to South Staffordshire custom—

	£	*s.*	*d.*	£	*s.*	*d.*
1 ton linseed cake, last year, two-thirds cost, at 12*l.* 10*s.*	8	6	8			
1 ton linseed cake, last year but one, one-third cost, at 12*l.* 10*s.*	4	3	4	12	10	0

According to my estimate of manure-value—

	£	*s.*	*d.*	£	*s.*	*d.*
1 ton linseed cake, last year, consumed with roots on land	3	18	8			
1 ton linseed cake, last year but one, fed with roots on land, followed by barley	1	12	4			
1 ton linseed cake, last year but two, fed with roots on land, followed by barley, and by grass or hay consumed	0	9	3	6	0	3
Difference				£6	9	9

Here, then, for every ton of linseed-cake annually consumed by his predecessor during the last years of his occupancy the incoming tenant would, according to the South Staffordshire custom, have to pay 6*l.* 9*s.* 9*d.* more than according to the estimate founded on manure-value, in fact more than twice as much.

In the following Table are compared the compensation that would be allotted according to the Lincolnshire custom, founded on original cost, and according to my estimates founded on composition or manure-value, for guano containing nitrogen equal to 13 per cent. ammonia, for guano containing nitrogen equal to 6·5 per cent. ammonia, for nitrate of soda containing nitrogen equal to 19 per cent. ammonia, for sulphate of ammonia con-

	One Ton used per Annum for Roots consumed.											
	Original value, or Purchasing Price.			Allowance according to Lincolnshire Custom.			Allowance according to scale at Page 26.			Custom allowance more (+) than according to scale at Page 26.		
	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*
Guano containing nitrogen = 13 per cent. ammonia ..	13	0	0	13	0	0	9	15	0	+3	5	0
Guano containing nitrogen = 6·5 per cent. ammonia.	13	0	0	13	0	0	4	17	6	+8	2	6
Nitrate of soda containing nitrogen = 19 per cent. ammonia	14	0	0	14	0	0	10	10	0	+3	10	0
Sulphate of ammonia containing 24 per cent. of ammonia	18	10	0	18	10	0	13	17	6	+4	12	6
Superphosphate of lime containing 26 per cent. soluble phosphate	5	10	0	5	10	0	2	15	0	+2	15	0

taining 24 per cent. ammonia, and for superphosphate of lime containing 26 per cent. phosphate rendered soluble. Each is supposed to be applied for a root-crop consumed by the outgoing tenant during the last year of his occupancy.

Again, in regard to manures, as to many feeding-stuffs, the compensation for unexhausted residue is much higher according to the Lincolnshire custom than according to my estimates. The illustration given of guano supposed to contain 13 per cent., or only 6·5 per cent. of ammonia respectively, each bought at the uniform price of 13*l.* per ton, shows how fallacious is the estimate of unexhausted value founded on original cost, instead of on composition.

The examples given in respect to both feeding-stuffs and manures, of the great and variable difference in the amount of compensation that would be awarded for unexhausted residue according to the customs of large agricultural districts on the one hand, and on the basis of valuation according to composition on the other, are, to say the least, very striking. Little doubt can be entertained, that much better evidence of their fairness and general applicability than at present exists would be required before attempting to apply the scale of allowances adopted in special agricultural districts to the country at large.

I am quite willing to grant that wide differences exist between the soil, climate, and other conditions of the agriculture of other districts, compared with those of my own farm. Indeed, although I cannot admit that the experimental results obtained at Rothamsted afford no data upon which, with care and judgment, important general conclusions applicable to other and different conditions may be founded, yet I have already said that, even supposing the basis upon which my own estimates of compensation are arranged were adopted, the exact scale of allowances might require considerable modification, according to the characters of the soil, of the climate, of the individual seasons, and other circumstances.

It will, perhaps, be said that so long as both parties interested agree to accept terms of compensation, which, whether fair or not, those subject to them may at some future time in their turn exact, no great harm is done. But in the event of a system of compulsory compensation being adopted, proof of the value of the unexhausted residue of feeding-stuffs and manures will be required of the claimant; and I would ask—where are the scientific witnesses, having characters to lose, who would assert that the unexhausted residue from all purchased feeding-stuffs and manures may be valued on the basis of the original value or purchasing price of the article?

SECTION III.—*Estimation of Compensation for the Unexhausted Residue of purchased (or saleable) Feeding-stuffs and Manures, by the Valuation of what is above ground, and has a recognised and easily-ascertainable Money-value.*

I freely admit that the tenant farmer has an equitable claim for compensation for the unexhausted manures he leaves in the soil when he quits his holding. But I think anyone who has carefully considered the schemes of compensation discussed in either of the foregoing Sections (I. and II.) of this Paper will agree with me that, even with the best intention, and calling to our aid all the knowledge, both practical and scientific, which we at present possess bearing upon the subject, it would be a matter of very great difficulty to lay down rules which shall be generally applicable for the estimation of the productive, and consequently of the money-value of the unexhausted residue of manures which have previously been applied to the soil, and have already yielded a crop.

The results of direct experiments have shown that some important constituents of manure either leave little or no unexhausted residue in the land after the first crop, or leave it so combined within the soil, or so distributed throughout it, that it produces little or no appreciable effect on succeeding crops. Some manures, on the other hand, produce marked effects for several years after their application. It is obvious, therefore, that it would require a very complicated sliding-scale to enable us to estimate the value of constituents already under ground under the very varying conditions that would arise, as to the description and the amount of the manure employed, the characters of the soil and subsoil, the dryness or wetness of the particular locality or of particular seasons, the description of crop grown, the cleanliness or foulness of the land, and so on.

It seems extremely desirable, therefore, that every attempt should be made to arrive at some mode of estimating the compensation due to an outgoing tenant for his unexhausted manures founded on the valuation of what is above ground, the amount and the value of which can be easily ascertained, rather than to leave his claims to be settled by the conflicts of practice and science in Courts of Law. Tenant-farmers would find an Act for compulsory compensation dearly bought on such terms.

In my Paper read before the London Farmers' Club, in April, 1870, I made some suggestions with a view of estimating compensation by the valuation of certain products of the farm. These, with some modifications, I propose to re-state here, in the hope that they will, at any rate, receive that full and candid

criticism without which the principle they involve should be neither accepted nor rejected.

If the plan in question were adopted, it would be desirable that the time of entry should be Lady-day. The items upon which I would base the valuation in favour of the outgoing tenant are,—

1. The farmyard-manure made during the last six months of the occupancy.
2. The manure from the consumption of purchased food which has not yet grown a crop.
3. The straw of the corn-crops of the next harvest.

The farmyard-manure would be valued to the incoming tenant by the load or ton. The price of the dung, per load or ton, would have to be settled, either by agreement, or by a recognised custom for a given district or locality; and the question is open for consideration whether the rate should approximate to the farm- or to the market-value. As the quantity of dung to be so valued will depend very much on the quantity of straw produced at the last harvest, the valuation will, so far, take into account the previous condition of the land. High condition of land means large corn-crops, and the tendency of the effect of high manuring is to increase the straw in greater proportion than the corn; and as 1 ton of straw makes from $3\frac{1}{2}$ to 4 tons or more of dung, the difference between the number of tons of dung paid for on entry on land in poor condition, and the amount to receive for on quitting in high condition, may be very large.

If in addition to the value of dung, reckoned per load or ton, the manure-value of the purchased food, if any, consumed in its production were also allowed, it might be objected that the incoming tenant would thus have to pay for the same manure twice over. In answer it may be said that the addition to the weight of a yard of manure by the excrements due to the consumption of purchased food is comparatively immaterial; but if it were decided that a reduction should be made on this score, about three-fourths of the weight of the purchased food would probably be sufficient to deduct from the total number of loads or tons of dung. What proportion of the original manure-value of the purchased food, as shown in Table I., at page 13, should be allowed, will depend upon whether it has been consumed on the land, or in the yards or buildings. If on the land 17*s*., and if in the yards or buildings 16*s*., for every 20*s*. of original manure-value should be allowed.

The condition of the land in regard to recent manuring would, as in the case of the amount of dung produced from the straw of the last harvest, be further represented in the amount of straw to be valued as such *at the next harvest*. How much the amount

of straw may vary on the same land and in the same seasons, according to "condition," may be illustrated by what is, however, admittedly a very extreme case. The continuously unmanured plot in my experimental wheat-field gave over a series of years an average of only about 14½ cwts. of straw per acre; whilst a highly-manured plot gave, over the same period, an average of 46½ cwts., or nearly 3¼ times as much.

Supposing the amount of straw were to be taken as an item in the valuation for compensation, as here proposed, the question whether the consuming or the market price should be adopted would, as in the case of the dung, be still open for consideration.

Shortly after the publication of my Paper read before the London Farmers' Club in 1870, Mr. Smith, of Woolston, writing in the 'Agricultural Gazette,' objected, first, that my plan of compensation would give the outgoing tenant nothing more than the consuming value of his straw, and afterwards, that it would give him no more than he could already obtain. Neither allegation was true. The real question at issue is, however, not whether on the plan proposed the outgoing tenant would receive less or more than under any other arrangement, but whether he would receive as much as he was entitled to for his outlay. In answer, I put as an example a case which, with some modifications, I repeat here.

Suppose a farm of 400 acres cultivated on the four-course system; that the tenant enters upon it in a low condition; that after years of clean farming, and the liberal use of purchased food and manures, he leaves it in high condition; and that, accordingly, it yielded at the time of entry, and the time of giving up, respectively, the following average amounts of produce.

	Average Produce per Acre.	
	On Entry.	On Leaving.
100 acres roots	6 tons.	12 tons.
100 acres barley	28 bushels.	42 bushels.
100 acres hay	1 ton.	2 tons.
100 acres wheat	24 bushels.	36 bushels.

It will be unnecessary to complicate the subject by taking into account the oats consumed by the horses, as the amount of manure produced from them would not be materially different at the two periods. Also for the sake of simplicity, the same proportion of straw to corn may be assumed on entry and on leaving,

though it would doubtless be higher under the improved condition. Let it be assumed, then, that in each case half the roots are consumed in the yards; that previous to entry no purchased food had been employed; that during the later years of the occupancy 25 tons of linseed-cake were used annually; that for every bushel of wheat (of 60 lbs.) there was an average of 100 lbs. of straw, and for every bushel of barley (of 52 lbs.) an average of 62½ lbs. of straw.

Adopting these data, the following are the amounts of straw, and the estimated amounts of dung, entered upon, and left, respectively; and the difference between the value of these on entry and on leaving, together with the proportion of the manure-value of the purchased cake, will represent the compensation to be received by the outgoing tenant for his improvement of the condition of the land.

First, as to the straw, we have—

	Wheat Straw.	Barley Straw.	Total Straw.	Value at 15*s.* per ton.
	Tons.	Tons.	Tons.	£ *s.* *d.*
On entry	107	78	185	138 15 0
On leaving	160½	117	277½	208 2 6
Difference	53½	39	92½	69 7 6

Reckoning the same amounts of straw as above assumed on entry, to have been converted into manure during the season previous to entry; and again, the same amounts as assumed on leaving, to have been converted into manure during the season previous to leaving; with, in each case, the consumption of roots and hay as above supposed, and previous to leaving of 25 tons of linseed-cake also, the amounts of manure, calculated according to carefully considered data would be about as follows:—

	Fresh Dung.	Value at 5*s.* per ton.
	Tons.	£ *s.* *d.*
On entry	649	162 5 0
On leaving	1072	268 0 0
Difference	423	105 15 0

Lastly, the estimated total *manure-value* obtained by the consumption of 1 ton of linseed-cake is 4*l.* 12*s.* 6*d.*; and assuming

that the outgoing tenant consumed 25 tons, half on the land and half in the yards, he would have an average claim of 16*s.* 6*d.* for every 1*l.* of original or total manure-value of the 25 tons of cake. The original manure-value of 25 tons of linseed-cake would be 115*l.* 12*s.* 6*d.*; and this at 16*s.* 6*d.* in the 1*l.* would be 95*l.* 7*s.* 10*d.*, due to the outgoing tenant on the consumption of the 25 tons of linseed-cake during the last year of his occupancy.

The outgoing tenant would, therefore, according to the above estimates, founded on the amount of certain products of the farm, the quantity and value of which are easily ascertained, receive as compensation for his unexhausted improvement in the condition of the land, the following sums beyond what he paid on entry :—

	£	*s.*	*d.*
On straw	69	7	6
On dung	105	15	0
On purchased food consumed	95	7	10
	£270	10	4

As I said at the time, so I repeat now, whether the above amount would or would not be adequate compensation is a question fairly open for discussion. I do not at all insist on the general applicability of the rate of 15*s.* per ton for the straw, or of 5*s.* per ton for fresh dung, adopted above for the purpose of illustration. All I contend for is the principle of valuation which I have proposed: being convinced that valuations so made would rest upon a basis of facts much more easily ascertainable, and much more trustworthy, than would any estimates of the value of the unexhausted residue of manures which have been applied to the land, and have already yielded a crop.

For comparison, there is shown below what would be the allowance in the case of a 400-acre farm as above assumed :—

1. According to the scale laid down in Section I., founded on *manure-value.*

2. According to the Lincolnshire custom, founded on *cost,* as quoted in Section II.

3. According to the valuation of the straw, of the dung, and of the manure from purchased food, as given above :—

1. According to *Manure-value*—	£	*s.*	*d.*	£	*s.*	*d.*
25 tons linseed-cake, last year, consumed with roots, half on land and half in yards	95	7	10			
25 tons linseed-cake, last year but one, consumed with roots, followed by corn	40	9	5			
25 tons linseed-cake, last year but two, consumed with roots, followed by corn, and hay consumed	11	11	3			
				147	8	6

2. According to *Lincolnshire custom*—

	£	s.	d.	£	s.	d.
25 tons linseed-cake consumed during last year, half original value	..			156	5	0

3. Calculated on produce, &c.—

	£	s.	d.	£	s.	d.
On straw	69	7	6			
On dung	105	15	0			
On purchased food consumed	95	7	10			
				270	10	4

Thus then, in the case supposed, the outgoing tenant would be awarded almost identical amounts of compensation for the unexhausted residue of his purchased linseed-cake, whether it were estimated according to my more elaborate mode of valuation founded on *manure-value*, or whether according to the Lincolnshire custom, founded on original value or *cost;* and the agreement would be closer still if, in the latter calculation, the present exceptionally high price of linseed-cake had not been adopted. As already pointed out, however, although in the case of linseed-cake, the food and manure-value of which are comparatively well understood, these two methods do give closely approximating results, yet, as has been shown, they lead to totally different estimates with other foods of different composition, and which have been less generally used.

Compared with either of the two methods just referred to, the valuation founded on the amount of dung made from the straw of the preceding harvest, the amount of purchased food consumed, and the quantity of straw of the succeeding harvest, is seen to give a very much higher rate of compensation. It is to be observed, however, that whilst in the case of method 1, or method 2, being adopted, further allowances would frequently be made for straw and dung, in the case of method 3 the allowance for these is already included.

With the foregoing consideration of the principle and results of the different methods, and with the example given of the application of each, put forward merely for the sake of illustration and comparison, I leave the further discussion of this complicated and difficult subject to those whom it may most concern, feeling assured that I may safely do so at a time when the important questions involved are exciting so much general interest.

It may be said that the adoption of the plan of valuation I have proposed, founded on the amount and value of certain products of the farm, would necessitate an entire re-arrangement of covenants and customs. This may be true; but I would suggest whether the changes required under such circumstances would be

greater than would be forced upon the landlord, if compulsory compensation on any other basis became the law of the land?

The main conclusions arrived at may be summarised as follows:—

1. In the existing state of our knowledge, no simple rules, applicable to various soils and subsoils, climates, seasons, crops, and manures, can be laid down for the valuation of the unexhausted residue of previously applied manures which have already yielded a crop.

2. Under such circumstances, valuation upon such a basis would very frequently result in injustice to the one party or the other, and would probably lead to much litigation.

3. If a system of compensation based upon the valuation of the unexhausted residue from purchased foods or manures were adopted, power should be given to the landlord, or to the incoming tenant, to take samples for analysis, of any foods or manures, for the use of which any claim is to be made.

4. In consideration of the difficulties attending other methods of valuation, it is very desirable to consider whether compensation for unexhausted condition of land might not be advantageously based upon the amount of certain products of the farm, the quantity and money-value of which can be easily ascertained.

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NOTE ON
THE OCCURRENCE OF "FAIRY-RINGS."

BY

J. H. GILBERT, PH.D., F.R.S., F.C.S.

IT is known that "Fairy-Rings" occur chiefly, though not exclusively, on poor pastures, and that they are discouraged by high (especially high nitrogenous) manuring. In the experiments on permanent meadow-land, conducted in Mr. Lawes's Park at Rothamsted, there are twenty different plots, representing nearly as many different conditions of manuring, the same condition having been continued on the same plot in most cases for twenty years in succession. Some of these plots yield an average of little more than 1 ton of hay per acre, and others more than 3 tons. On some "fairy-rings" occur, whilst on others they do not. The flora generally, so to speak, has, indeed, changed under the influence of the different manures in a very striking degree. Thus, speaking roughly, there are certain plots on which there develop annually from 40 to 50 species or more, whilst in others even less than 20 are in some seasons found. These differences, it should be remarked, are the result of the different conditions as to manuring, the whole area, so far as could be judged, having been pretty uniform in the character of the herbage at the commencement of the experiments.

It will be of interest, and be found not irrelevant to the special subject of this communication, to summarize as briefly as possible a few of the most characteristic changes which have taken place in the botanical character of the vegetation under the influence of certain characteristic conditions as to manuring. On three occasions, at intervals of five years (namely, in 1862, 1867, and 1872), a sample of the produce from each plot has been carefully taken and submitted to careful botanical analysis. Taking the average of the three separations, the following are some of the results:—

Continuously without manure (plots 3 and 12), the number of species found in the produce has averaged 48, of which 17 are grasses, 4 belong to the order of Leguminosæ, and 27 to other orders. The percentage by weight of grasses is about 62, that of the leguminous herbage 8, and that of the remaining species, which it will be convenient to term *miscellaneous* herbage, 30.

With a purely mineral manure, containing superphosphate of lime and sulphates of potass, soda, and magnesia, but no nitrogen or organic matter (plot 7), the average number of species found has been 42, of which, as without manure, 17 are grasses, 4 Leguminosæ, and the remainder "miscellaneous." But the produce has contained, on the average, only 55 instead of 62 per cent. of its weight of grasses, nearly 26 instead of only 8 per cent. (as without manure) of Leguminosæ, and only 19 instead of 30 per cent. of "miscellaneous" herbage.

With the same mineral manure as on the last plot (7), but with the addition of a large quantity of ammonia-salts, in plot 11, the average number of species found has been reduced to 21, of which 13 are grasses, 1 only belongs to the order of Leguminosæ, and 7 to other orders. But instead of 62 per cent. by weight of graminaceous herbage, as without manure, or 55 per cent., as with the mineral manure alone, we have now, with this mixture of the same mineral manure and a great excess of ammonia-salts, 92·5 per cent. by weight of grasses, only 0·01 per cent. of leguminous herbage, instead of 8 per cent. as without manure, and 26 per cent. with the purely mineral manure; and we have less than 7½ per cent. of species from other orders, instead of about 30 per cent. as without manure, or 19 as with the purely mineral manure.

It will be readily understood that, with the great variety of manurial conditions offered by the twenty different experimental plots, there is very great variety in the development and relative predominance of the representatives of different orders and genera intermediate between the marked extremes above referred to. With reference to the extreme cases cited, the prominent point to observe is, that the grasses dominate to an extraordinary degree where large quantities of ammonia as well as mineral manure were employed, whilst, under these conditions, the leguminous herbage was all but annihilated, and the "miscellaneous" species were very much reduced both in number and in weight per cent. in the produce. On the other hand, the percentage proportion and the actual quantity of the leguminous herbage was enormously increased by a mineral manure containing potass but no ammonia, or nitrogen in any other form, or organic matter of any kind.

Here is obviously a remarkable instance of domination under well-defined artificially induced conditions. But the facts are the more remarkable since it is the Graminaceous herbage (which

under equal conditions of ripeness contains a comparatively low percentage of nitrogen) that is so strikingly developed under the influence of nitrogenous manures; whilst the Leguminous herbage, which is characterized by a very high percentage of nitrogen, is specially developed by mineral manure containing potass; and when to this nitrogenous manures (especially ammoniacal) are added, the plants of the Leguminous order are almost abolished.

These striking results, brought out in experiments on the mixed herbage of grass-land, are moreover perfectly consistent with those observed in the growth of individual Graminaceous and Leguminous crops in rotation on arable land. Thus, a crop of wheat, barley, or oats is, other things being equal, very much increased by nitrogenous manures. A crop of clover or beans, on the other hand, although it may yield three, four, or five times as much nitrogen over a given area, as a crop of wheat, barley, or oats growing on the same description of land, is not characteristically benefited by direct nitrogenous manures. But these Leguminous plants will develop and assimilate an enormous amount of nitrogen under conditions in which the Graminaceæ would languish, and they at the same time leave the land in improved condition for the growth of the Graminaceæ. It must be admitted that the source of the much larger quantity of nitrogen assimilated over a given area by plants of the Leguminous than of the Graminaceous family, and of the residue of it left by them in the upper layers of the soil in a condition available for the Graminaceæ, is not yet conclusively explained.

Reflecting upon these facts, Mr. Lawes and myself have often felt that if we could determine the source of the nitrogen of the fungi growing in "fairy-rings," some light might perhaps be thrown on the question of the source of the nitrogen of the Leguminosæ which we cultivate separately in rotation, or which grow in association in the mixed herbage of grass-land.

It will be readily understood that the nearly twenty conditions as to manuring, and the as many different conditions as to flora, which the experimental plots in the Park at Rothamsted offer, afford an extremely favourable opportunity for observing the conditions, both as to manure and association, under which fungi, and especially those occurring in the so-called "*fairy-rings*," most readily develop. Accordingly for some time past Mr. Lawes has observed their occurrence and development; and it is the

results of his observations on these points that I am enabled to communicate.

Before stating under which of the conditions of manuring "fairy-rings" have most developed, it is of interest to observe that, according to published analyses of various fungi, generally from one fourth to one third of their dry substance consists of nitrogenous matters. The dry substance further generally contains from 8 to 10 per cent. of mineral matter or ash, of which about 80 per cent. is phosphate of potassium. In fact, fungi would appear to be among the most highly nitrogenous of plants, and to be also very rich in potass. Yet the fungi have developed in "fairy-rings" only on the plots poorest in nitrogen and potass in such conditions as to be available to most other plants.

To go a little further into detail:—

In November 1874 six species of fungi were observed on the unmanured plot (3), where also they were more abundant than on any other plot. They were named by the Rev. M. J. Berkeley as follows—*Boletus erythropus*, *Hygrophorus pratensis*, *H. coccineus*, *H. virgineus*, *Agaricus geotrupus*, *A. æruginosus*..

On the plot with superphosphate of lime alone (4 . 1) there were two species, namely *Hygrophorus coccineus* and *Clavaria vermicularis*.

On plot 8, with superphosphate of lime and sulphates of soda and magnesia, but without potass for fourteen years, two species, *Hygrophorus virgineus* and *Agaricus nudus*.

On plot 17, with nitrate of soda alone, small patches of *Hygrophorus virgineus* and of *Agaricus furfuraceus* were found. On plot 16, with nitrate of soda and sulphates of potass, soda, and magnesia, a few of *Hygrophorus virgineus*. And on one or two other plots there were individual specimens of *Agaricus arvensis* of very large size.

"Fairy-rings" occurred almost exclusively on plot 4 . 1 (with superphosphate of lime alone), and on plot 8 (with superphosphate of lime, and sulphates of soda and magnesia, but no potass).

In May 1875 only one species, namely *Marasmius oreadum*, was observed.

On the 19th there were comparatively few specimens to be found. On the 31st they occurred in small numbers on plot 1 (with farm-yard manure and ammonia salts 1856–1863, but since ammonia salts only), on plot 2 (with farm-yard manure alone 1856–

1863, but since unmanured), on plot 3 (unmanured for more than twenty years), and on plot 7 (with superphosphate of lime and sulphates of potass, soda, and magnesia for twenty years). On plots 4.1 and 8, on the other hand, they could be counted by hundreds; and on these two plots only were they found in "fairy-rings."

On plot 4.1 (with superphosphate of lime alone) there were six more or less complete "fairy-rings," on some of which hundreds of the fungi were growing in thick patches, generally surrounded by the very luxuriant grass of the ring.

On plot 8 (with superphosphate of lime and sulphates of soda and magnesia but no potass for fourteen years) there were three large "fairy-rings" with the fungi growing very thickly on them, the grass of the rings being also very luxuriant. There were, besides these rings, a number of patches down one side of the plot showing many of the fungi and very luxuriant grass; and there was one large patch of very luxuriant grass showing no fungi now, nor was mycelium found in the soil; but in the autumn this patch gave a crop of *Agaricus nudus*. On this plot especially the increased growth of grass on the rings and patches where fungi have occurred is so considerable that it must appreciably affect the amount of produce on the plot; and the grasses most favoured seem to be *Poa trivialis* and *Holcus lanatus*.

Thus, then, the highly nitrogenous fungi flourished strikingly, and appeared in "fairy-rings," on two plots only, on neither of which is either nitrogen or potass applied as manure—conditions under which the development of the Graminaceæ is extremely restricted, and their limited growth is due to a deficient available supply of nitrogen, or of potass, or of both, and where the competition of the Leguminosæ is also weak, in the absence of a more liberal supply of potass.

The questions obviously arise whether the greater prevalence of fungi under such conditions be due to the manurial conditions themselves being directly favourable for their growth, or whether other plants, and especially the grasses, growing so sluggishly under such conditions, the plants of the lower orders are the better able to overcome the competition and to assert themselves. On this point the further questions arise whether the fungi prevail simply in virtue of the absence of adverse and vigorous competition, or whether to a greater or less extent as parasites, and so at the expense of the sluggish underground growth of the plants in

association with them; or, lastly, have these plants the power of assimilating nitrogen in some form from the atmosphere, or in some form or condition of distribution within the soil not available (at least when in competition) to the plants growing in association with them?

It is with the hope of arriving at some answer to these questions, either from the existing knowledge or the future observation of botanists and vegetable-physiologists, that we have felt it desirable to comply with the request made to us, to bring our own observations, made from a special point of view, before the Fellows of the Linnean Society. In aid of this object it may be well to state some other facts which we have noticed in connexion with the formation and extension of "fairy-rings."

It is probable that the fungi growing on meadow-land owe their occurrence in the first instance to the accidental droppings of animals or birds. Individual specimens appear, and sometimes grow to a large size, even on some of the highly manured plots; but patches, or "rings," are chiefly found on the poorly manured or exhausted plots—that is to say, where there is a marked absence of luxuriance in the vegetation generally. So far as may be judged from observation hitherto, patches may form and die out without development and extension into "rings." The formation of an annually increasing "ring" seems to require special conditions, both as to soil and association. In the case of mere patches, some examinations of the soil in spring and autumn have not shown a marked development of mycelium where it would be expected if there were to be extension, though it would appear that, if the conditions be specially favourable, they may enlarge and endure for some time. In the case of extending "rings," on the other hand, the soil under the outer portion of the circle generally shows, to a depth of a foot or more, according the character of the soil, an enormous development of mycelium for some time prior to the appearance of the above-ground growth.

It is to be particularly observed that this development of mycelium is always under the *outer* portion of the "ring," and is not found within it. When a ring is formed, what happens seems to be the following:—From some extraneous cause, such as above referred to, a patch of fungi is established. The plants falling and dying supply a rich nitrogenous (as well as mineral) manuring to the adjacent herbage. A patch of dark green luxuriant grass, generally several inches higher than the surrounding herbage,

succeeds. This being cut or eaten off, the soil may sooner or later become even more exhausted than before; and it is accordingly frequently observed that the grass within is less luxuriant than that outside the ring. Initiative experiments, upon which, however, we would not place implicit reliance, have, indeed, shown a lower percentage of nitrogen in the surface soil within the circle than at an equal depth either under or without the circle. Leguminous plants are not excluded from the area within the ring; but whilst *Lathyrus pratensis* and *Trifolium pratense*, plants which on the land in question have shown themselves very dependent on artificial supplies of potass, seem to be discouraged, *Lotus corniculatus* and *Trifolium repens*, species which maintain their position under marked conditions of exhaustion of soil, are fairly abundant. At any rate, it would appear that, in the case of "rings," the soil underneath the fungus-growth has become unfitted to support another crop, or successive crops, of fungi. Accordingly, supposing the soil of the plot to be favourable, the ring develops always outwards—that is, on what is to the fungi virgin soil; and hence the annual enlargement.

It will be seen that in these facts we have an interesting illustration of what may be called natural rotation. The original fungi probably receive their nutriment from extraneous sources; but once established, they must, for the extension into "rings," depend upon other supplies, which, if due to the soil itself, are obviously unfavourable, either in condition or in distribution, to the surrounding vegetation, and especially to the grasses, which do not flourish until the matter taken up by the fungi becomes available to them as manure, when at once they show very great luxuriance. Or is it, as already suggested, that the mycelium develops, so far as its nitrogen is concerned, not at the expense of that which may be said to have become a constituent of the soil itself, but of that accumulated in the vegetable débris from former growth within the soil, or even parasitically—that is, at the expense of the nitrogenous matters of the roots of not dead but very sluggish vegetation?

These points are obviously of very considerable interest from both a chemical and a physiological point of view; and it is much to be hoped that botanists and vegetable physiologists who may have special knowledge on the subject will bring it to bear on the questions which seem to be at issue—or that, in so far as such knowledge is not yet available, some may be induced to take up

the investigation with a view to the elucidation of that which, to us at least, seems to require explanation *.

* Owing to pressure of occupation at the time, I was not able to refer to the opinions of others before writing the foregoing notes, but have since done so, and would call attention to the observations of Berkeley, Way, Buckman, Lees, and others.—J. H. G.

ON SOME POINTS IN CONNECTION WITH VEGETATION.

BEING AN ADDRESS DELIVERED AT SOUTH KENSINGTON, IN THE CHEMICAL SECTION OF THE SCIENCE CONFERENCES, MAY 18, 1876.

BY DR. J. H. GILBERT, F.R.S., F.L.S., F.C.S.

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On Some Points in Connection with Vegetation.

By Dr. J. H. Gilbert, F.R.S., F.L.S., F.C.S.

The subject of vegetation is such a very wide one, and might be treated of in so many different ways, that it seems desirable to state at the outset what is the scope, and what are the limits, of the discussion which I propose to bring before you. I propose, then, to confine attention almost exclusively to the question of the sources of the nitrogen of vegetation in general, and of agricultural production in particular. I propose further to treat of this subject mainly in the aspects in which it has forced itself upon the attention of Mr. Lawes and myself during the now thirty-three years of our agricultural investigations; and, also, in so far as it illustrates, and is illustrated by, the objects contributed by Mr. Lawes to the Exhibition around us.

Before entering upon the special subject matter of my discourse, I must claim the indulgence of those present who are already well acquainted with the main facts of the chemistry of vegetation, whilst I call attention, very briefly, to some rather elementary matters, with a view of rendering what has to follow the more intelligible to any who may be less fully informed on the subject.

When a vegetable substance is burnt—as a familiar instance, let us say tobacco, for example—the greater part of it is dissipated, but there remains a white ash. The ashes of crude or unripe vegetable substances are found on analysis to contain most, or all, of the following constituents, namely:—

Oxide of iron, oxide of manganese, lime, magnesia, potash, soda, phosphoric acid, sulphuric acid, chlorine, and silica.

Rarer substances than these are also sometimes found. Now, much has of late years been established in regard to the occurrence, and the offices, of some of these substances in plants; but I do not propose to touch upon the questions herein involved. It will suffice further to say in regard to these incombustible, or "mineral," constituents, that the ash of one and the same description of plant, growing on different soils, may, so long as it is in the growing or immature state, differ very much in composition. Again, the ashes of different species, growing on the same soil, will differ very widely in the proportion of their several constituents. But it is found that the nearer we approach to

the elaboration of the final products of the plant—the seed, for example—the more fixed is the composition of ash of such products of one and the same species. In other words, there is very little variation in the composition of the ash of one and the same description of seed, or other final product, provided it be evenly and perfectly matured. This fact alone, independently of all that has been established of late years in regard to the office or function, so to speak, of individual mineral constituents of plants, would be sufficient to indicate the essentialness of such constituents for healthy growth ; and it is obvious that they must be provided *within the soil.*

But now as to the combustible constituents—the carbon, the hydrogen, the oxygen, and the nitrogen. Leaving out of consideration such exceptional cases as those brought to light in Mr. Darwin's beautiful investigation on insectivorous plants, and also the sources of the organic substance of fungi, and perhaps of some forced horticultural productions, it may be stated that the source of the carbon of vegetation generally is the carbonic acid existing in very small proportion, but in large actual amount, in the atmosphere ; that the source of the hydrogen is water ; and that the source of the oxygen may be either that in carbonic acid, or that in water. With regard to the nitrogen the case is, however, by no means so simple. Not that there are no questions still open for investigation in regard to the assimilation by plants of their incombustible or mineral constituents, or of their carbon, their hydrogen, and their oxygen ; but those relating to the sources, and to the assimilation, of their nitrogen, are not only in many respects of more importance, but seem to involve greater difficulties in their solution.

What, then, are the sources of the nitrogen of vegetation? Are they the same for all descriptions of plants? Are they to be sought entirely in the soil? or entirely in the atmosphere? or partly in the one, and partly in the other?

As the combined nitrogen coming down from the atmosphere in rain, hail, snow, mists, fog, and dew, does undoubtedly contribute to the annual yield of nitrogen in our crops, let us first briefly consider what is known as to the amount of it annually so coming down over a given area of the earth's surface ; and as we are here discussing the subject in England, I will adopt the English pound as the unit of weight, and the English acre as the unit of area. The following table shows the amount of nitrogen coming down as ammonia and nitric acid in the total rain, hail, snow, and some of the minor deposits

during the years 1853, 1855, and 1856, at Rothamsted (Herts), the nitric acid being in all cases determined by Mr. Way, and the ammonia in some cases by him, and in others by ourselves :—

TABLE I.

Combined Nitrogen in Rain and Minor Aqueous Deposits at Rothamsted.

	Nitrogen per acre, per annum, lbs.			
	1853.	1855.	1856.	Mean.
As ammonia	5·67	5·86	7·85	6·46
As nitric acid... ...	(not determined)	0·77	0·73	0·75
Total		6·63	8·58	7·21

Numerous determinations of the ammonia and nitric acid in rain, and the other aqueous deposits, have been made in various parts of France and Germany, some in the vicinity of towns, and some in the open country. Of the latter, which are the most to our purpose, it may be stated that those of Boussingault at Liebfrauenberg, in Alsace, generally indicate a larger proportion of the nitrogen existing as nitric acid, and less as ammonia than our own ; but, upon the whole, the observations in the two widely separated localities mutually confirm one another. Of the results of others, in other localities, some show about the same amount of combined nitrogen so deposited as our own, some, however, much more, and some much less, than ours ; but the determinations on the Continent generally show a higher proportion of the total combined nitrogen to exist as nitrates than those in this country. It may be added, that numerous determinations of the combined nitrogen in rain, dew, &c., collected at Rothamsted, have much more recently been made by Professor Frankland, and his results, which are published in the "Sixth Report of the Rivers Pollution Commission," are substantially confirmatory of the earlier determinations, summarized in the foregoing Table, but upon the whole they indicate lower amounts. Lastly, M. Marié-Davy determined the ammonia in the rain, &c., collected at the Meteorological Observatory at Montsouris, Paris, during the last six months of 1875 ; and the amount of ammonia so coming down, even within the walls of Paris, only represented 5·25 lbs. of combined nitrogen per acre, or only 10·5 lbs. per acre, per annum. M. Marié-Davy did not make a complete series of determinations of the nitric acid in the meteoric waters, but his initiative results agree with the experiments of others in showing the amount of combined nitrogen so existing to be comparatively small.

Thus, the determinations hitherto made of the amount of combined nitrogen coming down in the measured aqueous deposits from the atmosphere, do not justify us in assuming that the quantity available from that source will exceed 8 or 10 lbs. per acre, per annum, in the open country, in Western Europe. It should be observed, however, that the amount of ammonia especially is very much greater in a given volume of the minor aqueous deposits than it is in rain ; and there can be little doubt that there would be more ammonia deposited from them within the pores of a given area of soil, than on an equal area of the non-porous even surface of a rain-gauge. How much, however, would thus be available to the vegetation of a given area beyond that determined in the collected and measured aqueous deposits, we have not the means of estimating with any certainty. On the other hand, numerous independent determinations, by both Dr. Voelcker and Dr. Frankland, of the nitric acid in the drainage-water collected from land at Rothamsted which had been many years unmanured, lead to the conclusion that there may be a considerable annual loss of nitrogen by the soil in that way.

The next point to consider is, what is the amount of nitrogen annually obtained over a given area, in different crops, when they are grown without any supply of it in manure. This point may be illustrated by the results obtained in the field experiments on Mr. Lawes' farm at Rothamsted, which have now been in progress for about a third of a century. Table 2, which follows, shows the yield of nitrogen per acre, per annum, in wheat, in barley, and in root crops, each grown for many years in succession on the same land, either without any manure, or with only a complex mineral manure, that is supplying no nitrogen.

TABLE II.

Yield of Nitrogen per acre, per annum, in Wheat, Barley, and Root Crops, at Rothamsted.

Crop, &c.	Condition of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
			lbs.
Wheat	Unmanured	8 yrs. 1844-'51	25·2
		12 yrs. 1852-'63	22·6
		12 yrs. 1864-'75	15·9
		24 yrs. 1852-'75	19·3
		32 yrs. 1844-'75	20·7
	Complex Mineral Manure ...	12 yrs. 1852-'63	27·0
		12 yrs. 1864-'75	17·2
		24 yrs. 1852-'75	22·1

TABLE II.—*continued.*

Crop, &c.	Condition of Manuring, &c.		Duration of Experiment.	Average Nitrogen per acre, per annum.
				lbs.
Barley	Unmanured		12 yrs. 1852-'63	22·0
			12 yrs. 1864-'75	14·6
			24 yrs. 1852-'75	18·3
	Complex Mineral Manure ...		12 yrs. 1852-'63	26·0
			12 yrs. 1864-'75	18·8
			24 yrs. 1852-'75	22·4
Root Crops	Complex Mineral Manure	Turnips ...	8 yrs. 1845-'52	42·0
		Barley	3 yrs. 1853-'55	24·3
		Turnips ...	15 yrs. 1856-'70[1]	18·5
		Sugar-beet...	5 yrs. 1871-'75	13·1
		Total	31 yrs. 1845-'75	26·8

Bearing in mind what has been said as to the amount of combined nitrogen known to be annually deposited from the atmosphere, the figures in Table II. have great interest and significance. Thus, over a period of 32 years, the wheat has yielded an average of 20·7 lbs. of nitrogen, per acre, per annum, without manure. But if we look at the quantities yielded during the first 8, the next 12, and the last 12 years of that period, it is seen that there has been a gradual, but at the same time a considerable decline in the annual yield. From this it would appear probable that the nitrogen of the soil, derived from previous accumulations, is being gradually reduced. Whether or not the whole of the excess of yield over that available from the rain, and other measured aqueous deposits from the atmosphere, is due to previous accumulations within the soil, and is therefore inducing a gradual exhaustion of its stock of nitrogen to that extent, we have not conclusive evidence to show. Determinations of nitrogen in samples of the soil taken at different times during the course of the experiments do, indeed, show an appreciable reduction. It is probable, however, that a part of the excess of yield is due to condensation of ammonia within the pores of the soil, beyond that which would be deposited in rain, and in the dew and other minor deposits condensed on the non-porous even surface of a rain-gauge, as already referred to.

Excluding the first 8 years of the growth of wheat, it is seen that whilst over the next 24 years, 1852-1875, the wheat yielded 19·3 lbs.

[1] Thirteen years' crop—two years failed.

of nitrogen, per acre, per annum, the barley yielded an average of 18·3 lbs. over the same period. Again, during the first 12 of the 24 years, the wheat yielded 22·6 lbs., and the barley 22 lbs.; whilst, during the second 12 years, the yield in wheat was reduced to 15·9, and that in the barley to 14·6 lbs. The similarity in the yield of nitrogen over the same periods in these two closely allied crops, growing in different fields, is very striking, though, upon the whole, the indication is that the autumn-sown wheat has accumulated more than the spring-sown barley.

It is next to be observed that the annual use of a complex mineral manure has but very slightly increased the yield of nitrogen in either of these gramineous crops; and it is probable that the increased yield, such as it is, is derived from the previous accumulations within the soil, and not from atmospheric sources.

To sum up the evidence in regard to the sources of the nitrogen of these two typical gramineous plants, when none of it is supplied to them by manure, though it is not conclusively shown whence the whole of it is derived, it would at any rate appear probable, that it may be accounted for by the combined nitrogen coming down in rain, and in the other measured aqueous deposits from the atmosphere, by the condensation of the ammonia of the air within the pores of the soil, and by the previous accumulations within the soil.

Let us now consider what is the yield of nitrogen by plants of other natural families, and first of all by certain so-called "root-crops"—turnips of the natural order cruciferæ, and sugar beet of the order chenopodiaceæ. On this point we have the experience of 31 years, excepting that during three of those years barley was grown without any manure in order to equalise the condition of the land as far as possible before re-arranging the manuring, and during 2 other years the turnips failed and there was no crop.

It should be premised that when root-crops are grown without manure of any kind, there is after a few years scarcely any produce at all; and hence the results recorded in the table are those obtained by the use of mineral manures, but without any supply of nitrogen. It is seen that during the first 8 years of turnips, there was an average yield of 42 lbs. of nitrogen per acre per annum. During the next 3 years barley yielded 24·3 lbs. annually. During the next 15 years, 13 with Swedish turnips, and 2 without any crop, there was a yield of 18·5 lbs. per acre annually. During the last 5 years sugar-beet yielded 13·1 lbs. per acre per annum. Lastly, over the whole 31 years,

during which there were 3 crops of barley, 2 years without any crop, 21 years of turnips, and 5 of sugar-beet, the average annual yield was 26·8 lbs. of nitrogen.

Here, then, we have a reduction to less than one-third during the later compared with the earlier years, and to a lower point than even with either wheat or barley; though, during the whole period, the annual yield is higher than with either of the two gramineous crops. It may be mentioned that we have other experimental evidence showing that the so-called "root-crops" exhaust at any rate the superficial layers of the soil of their available supplies of nitrogen, more completely than perhaps any other crop. It may further be added that the surface soil has shown during recent years a lower percentage of nitrogen than that of any of the other experimental fields. We have fair grounds for concluding, therefore, that if in the cases of the wheat and the barley the nitrogen yielded beyond that retained by the soil from the direct measurable aqueous deposits, together with that condensed within the pores of the soil, from the atmosphere, be derived from previous accumulations within the soil, so also may the excess of yield by the so-called "root-crops" be accounted for.

We now come to the consideration of the yield of nitrogen when plants of the *leguminous* family are separately grown, or when they, and plants of some other families, are grown in alternation, or in association, with the gramineæ. Table III. shows the results obtained with beans, and with clover; with clover and barley grown in alternation; and with turnips, barley, clover or beans, and wheat, grown in an actual course of rotation.

TABLE III.

Yield of Nitrogen per Acre per Annum in Beans, in Red Clover, and in Rotation.

Crop, &c.	Conditions of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
			lbs.
Beans	Unmanured	12 yrs. 1847-'58	48·1
		12 yrs. 1859-'70(1)	14·6
		24 yrs. 1847-'70	31·3
	Complex Mineral Manure ...	12 yrs. 1847-'58	61·5
		12 yrs. 1859-'70(1)	29·5
		24 yrs. 1847-'70	45·5

(1) 9 years Beans, 1 year Wheat, 2 years Fallow.

TABLE III.—*continued.*

Crop, &c.	Conditions of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
Clover	Unmanured	22 yrs. 1849-'70[1]	30·5
	Complex Mineral Manure ...	22 yrs. 1849-'70[1]	39·8
Barley	Unmanured	1 yr. 1873	37·3
Clover		1 yr. 1873	151·3
Barley	Unmanured ... After Barley	1 yr. 1874	39·1
	After Clover	1 yr. 1874	69·4
	Barley after Clover more than after Barley	... ...	30·3
Rotation 7 Courses	1 Turnips, 2 Barley, 3 Clover or Beans, 4 Wheat — Unmanured	28 yrs. 1848-'75	36·8
	Superphosphate ...	28 yrs. 1848-'75	45·2

Referring first to the results obtained with beans, the table shows that without manure there was an annual yield over the first 12 years, 1847—1858, of 48·1 lbs. of nitrogen. Over the next 12 years, 1859—1870, it was reduced to 14·6 lbs. per acre per annum. Still, over the whole period of 24 years, we have an annual yield of 31·3 lbs., or more than one and a half time as much as in either wheat or barley.

In the case of wheat and barley it was seen that a mixed mineral manure increased the yield of nitrogen to a very small degree only. Not so in the case of the leguminous crop, beans. During the first 12 years a complex mineral manure, containing a large amount of potash —I call attention to this fact because we have abundant evidence that it is the potash chiefly that is effective—gave 61·5 lbs. of nitrogen per acre per annum, against 48·1 lbs. obtained over the same period without manure. During the next 12 years, the potash manure gave 29·5 lbs. against scarcely half as much, or 14·6 lbs. without the potash manure. And finally, during the whole period of 24 years, the potash manure has given 45·5 lbs. of nitrogen per acre per annum, against 31·3 lbs., or only about two-thirds as much, without manure; and we have more than twice as much yielded by a potash manure over a period of 24 years with beans than with either wheat or barley.

[1] 6 years Clover, 1 year Wheat, 3 years Barley, 12 years Fallow.

Before calling attention to the figures relating to another leguminous crop—red clover—it should be mentioned that leguminous crops generally are, and clover in particular is, extremely sensitive to adverse climatal circumstances; but clover is pre-eminently sensitive to soil conditions also. Indeed, it is a fact well recognised in agriculture, that few soils can be relied upon to grow a good crop of clover oftener than once in about 8 years; and many soils will not yield it so frequently. It will not excite surprise, therefore, that in attempting to grow clover year after year on the same land, we have only succeeded in getting any crops, and some of those poor ones, in 6 years over a period of 22. Indeed, the plant failed seven times out of eight during the winter and spring succeeding the sowing of the seed; when, in some cases a crop of wheat or barley was taken, and in others the land was left fallow. Hence, over a period of 22 years we have had only 6 years of clover, one of wheat, three of barley, and twelve of fallow. Still, the annual yield of nitrogen over the 22 years was 30·5 lbs. without any manure, and 39·8 lbs., or nearly one-third more, by mineral manure containing potash. Unfavourable as was this experiment in an agricultural point of view, still it is seen that the influence of the interpolation of this leguminous crop has greatly increased the yield of nitrogen compared with that obtained in either wheat or barley grown continuously; and that, unlike the result with those crops, a potash manure has here again, as with beans, greatly increased the yield.

Without attempting for the moment to discuss the probable source or sources of this greatly increased yield of nitrogen by leguminous as compared with gramineous crops, I will simply here remark in passing that we have no evidence leading to the conclusion that this increased assimilation is at the expense of the nitrogen existing at any rate in the upper layers of the soil. In fact, such initiative results as we have relating to the nitrogen in the soil of the experimental bean field would rather lead to the conclusion that the better the crop has grown, and the more nitrogen it has assimilated, the richer rather than the poorer in nitrogen (as indicated by the soda-lime method) has the surface soil become. To this point, however, we shall have to recur presently; but in the meantime let us first refer to the yield of nitrogen in other cases in which leguminous crops have been interpolated with others.

It is, indeed, well known that the growth and removal of a highly nitrogenous leguminous crop is one of the best possible preparations for the growth of a gramineous corn crop, which characteristically

requires nitrogenous manuring. A striking illustration of this apparent anomaly is afforded in the results next in order recorded in the Table III.

After the growth of six corn crops in succession by artificial manures alone, barley was grown without manure in 1873 on one portion of the same land; and on another portion clover was grown. It is calculated that there were taken off in the barley 37·3 lbs. of nitrogen, and in the three cuttings of clover 151·3 lbs. Yet, in the next year, 1874, barley succeeding the barley gave 39·1 lbs., and barley succeeding the clover gave 69·4 lbs. of nitrogen; or 30·3 lbs. more after the removal of 151·3 lbs. in clover than after the removal of 37·3 lbs. in barley. Nor was this remarkable result to be explained by either accident or error. For, determinations of nitrogen in four separately taken samples of the soil, in the mixture of the four, and in the mixture of six others, taken from each plot and at different depths, all concurred in showing an appreciably higher percentage of nitrogen, especially in the surface soil, 9 inches deep, of the land from which the clover had been removed than in that from which the barley had been taken; and this was so, although, in every case, all visible vegetable debris had been carefully picked out. Here, then, the surface soil at any rate was positively enriched in nitrogen (determinable by soda-lime) by the growth and removal of a very highly nitrogenous crop. It may be mentioned that Dr. Voelcker has obtained results of a similar character.

The results next to be considered are those obtained in an actual four-course rotation of crops—namely, turnips, barley, clover or beans, and wheat. The experiments have been conducted through seven such courses; that is to say, over a period of twenty-eight years. One portion of the land, the results relating to which are given in the table, has been entirely unmanured during the whole of that period, and the other has received super-phosphate of lime alone, once every four years—that is to say, for the turnips commencing each course; but it has received no other manure throughout the 28 years, either mineral or nitrogenous.

Under these conditions—that is, with a turnip crop and a leguminous crop interpolated with two gramineous crops—we have, without manure of any kind, an average of 36·8 lbs. of nitrogen yielded per acre, per annum; or not far from twice as much as was obtained with either of those cereal crops, wheat or barley, grown consecutively. With super-phosphate of lime alone, which, in a striking degree increased the yield of nitrogen in the turnips, reduced it in the succeeding barley, increased it greatly in the leguminous crops, and slightly in

the wheat immediately following them, we have the average annual yield of nitrogen raised to 45·2 lbs. per acre, per annum, over the 28 years; or to more than double that obtained by wheat or barley grown continuously by mineral manures alone. And it may be observed that where, in adjoining experiments, no leguminous crop was grown between the barley and the wheat, but the land was fallowed instead, the total yield of nitrogen in the rotation was very much less: the wheat succeeding the fallow yielding very little more nitrogen than that succeeding the leguminous crops which had removed so much of it. In other words, the removal of the most highly nitrogenous crops of the rotation—beans or clover—has been succeeded by a growth of wheat, and assimilation of nitrogen by it, almost as great as when it has succeeded a year of fallow—that is to say, a period of accumulation from external sources, and no removal by crops.

One other illustration must be given of the power of plants of the leguminous and some other families to assimilate more nitrogen over a given area than those of the gramineous family. But before entering upon the bearing of the results in question on this particular point, it will be necessary to digress a little to call special attention to the conditions of the experiments under which the results were obtained; and it is the more desirable to do this, since the most important of Mr. Lawes' contributions to this Exhibition is an illustration of the results I am about to refer to.

I must here forestall a little what I shall have to refer to more fully further on, as to the effects of characteristically different manuring substances on crops belonging to different botanical families. I will say briefly, then, that it is found that nitrogenous manures have generally a very striking effect in increasing the growth of gramineous crops grown separately on arable land, such as wheat, barley, or oats, all of which contain a comparatively small percentage of nitrogen, and, as has been illustrated, assimilate a comparatively small amount of it over a given area when none is supplied to them in manure. The highly nitrogenous leguminous crops, on the other hand, such as beans, peas, clover, and others, are by no means characteristically benefited by the use of direct nitrogenous manures, such as ammonium-salts or nitrates, though nitrates act much more favourably than ammonium-salts. Again, whilst, under equal conditions of soil and seasons, mineral without nitrogenous manures increase comparatively little the poor-in-nitrogen gramineous crops that are grown separately, such manures, and especially potash-manures, as has been seen, increase

in a striking degree the growth of crops of the leguminous family grown separately, and coincidently the amount of nitrogen they assimilate over a given area.

Such, then, is the result obtained in the separate growth, on arable land, of individual plants of the different families. Now, in the mixed herbage of permanent grass land, we may have fifty, or even many more species growing together, representing nearly as many genera and perhaps eighteen or twenty natural orders or families. Of these the gramineæ generally contribute the largest proportion of the herbage; and, on good grass land, if the leguminosæ do not come second they are at any rate prominent. The degree in which other orders are represented may be very various indeed, according to soil, locality season, and other circumstances. In Mr. Lawes' park, at Rothamsted nearly eighty species have been observed; but of many only isolated specimens, and it may be stated generally that about fifty species are so prominent as to be found in a carefully averaged sample of the hay grown without manure.

Experiments on the influence of different manures on this mixed herbage were commenced in 1856; at which time the herbage was apparently pretty uniform over the whole area selected. About twenty plots, from one-quarter to one-half an acre each, were marked out, of which two have been left continuously without manure, and each of the others has received its own special manure, and as a rule the same description year after year—and the experiments have now been conducted over a period of twenty years.

Under this varied treatment, changes in the flora, so to speak became apparent even in the first years of the experiments; and three times since their commencement, at intervals of five years—namely, in 1862, 1867, and 1872—a carefully averaged sample of the produce of each plot has been taken and submitted to careful botanical separation, and the percentage, *by weight*, of each species in the mixed herbage determined. Partial separations have also been made in other years.

Mr. Lawes has contributed a large case of specimens to the Exhibition, which shows the botanical composition of the herbage on twelve selected plots in the seventeenth season of the experiments (1872). The quantities of the different plants there exhibited represent the relative proportion, by weight, in which each species was found in the mixed produce of the different plots; and the whole illustrates in a striking manner the domination of one plant over another, under the influence of different manures, applied year after year on the same plot.

The general results of the experiments may be briefly summarised as follows :—

The mean produce of hay per acre per annum has ranged, on the different plots, from about 23 cwt. without manure to about 64 cwt. on the plot the most heavily manured.

The number of species found has generally been about 50 on the unmanured plots, and has been reduced to an average of only 20, and has sometimes been less, on the most heavily manured plots.

Species belonging to the order *Gramineæ* have, on the average, contributed about 68 per cent. of the weight of the mixed herbage grown without manure ; about 65 per cent. of that grown by purely mineral manures (that is, without nitrogen) ; and about 94 per cent. of that grown by the same mineral manures, with a large quantity of ammonium-salts in addition.

Species of the order *Leguminosæ* have, on the average, contributed about 9 per cent. of the produce without manure, about 20 per cent. of that by purely mineral manures (containing potash), and less than 0·01 per cent. of that by the mixture of the same mineral manures and a large quantity of ammonium-salts.

Species belonging to various other orders have, on the average, contributed about 23 per cent. of the produce without manure ; about 15 per cent. of that by purely mineral manures, and only about 6 per cent. of that by the mixture of the mineral manures and a large amount of ammonium-salts.

Not only the amounts of produce, but the number and description of species developed, have varied very greatly between the extremes here quoted, according to the particular character or combination of manure employed, and to the character of the seasons, as is strikingly illustrated by the arrangement of the specimens in the case, which, however, it should be borne in mind, show the composition of the herbage on the selected plots in one particular season only—namely, in 1872.

Obviously, these few remarks can only very inadequately indicate the interest of these curious illustrations of the domination of one plant over another in the mixed herbage of permanent grass-land. Nor do we pretend to be able to give a satisfactory explanation of the variations induced, founded on the obvious or recorded difference in above-ground or under-ground character or habit of growth of the individual species. The whole of the results—agricultural, chemical, and botanical—obtained during the twenty years of the experiments are, however, now in course of arrangement for publication ; and that

we may not overlook such explanations as might be suggested from the point of view of the botanist and vegetable physiologist, as well as that of the chemist, we have associated with ourselves Dr. Masters in working up the botanical part of the inquiry ; and I think Dr. Masters will agree with me in saying that much more has yet to be known of the difference in the physiological capability, so to speak, of the leaves of plants of different species, genera, and orders, and of the difference in the distribution, and in the feeding power, of the roots, before satisfactory explanations of the facts observed can be given. Surely, a wide field of investigation for the botanist and vegetable physiologist is here opened up to view !

Let us now recur to the question of the various amounts of nitrogen assimilated over a given area by plants of different natural orders, and call attention to the facts bearing upon the point which these experiments on the mixed herbage of grass land have supplied.

In Table IV. is shown the average produce (in the condition of hay) in lbs., per acre, per annum, over 20 years, of herbage of the gramineous family, of herbage of the leguminous family, and of herbage of other orders, calculated according to the mean percentage of each of these, determined in separations at six periods, namely in 1862, 1867, 1871, 1872, 1874, and 1875, in samples of the produce of four of the plots which have received no nitrogenous manure from the commencement ; and there is also given, by the side of these results, the average annual yield of nitrogen per acre over the first 10, the second 10, and the total period of 20 years, in each case.

TABLE IV.

Yield of Nitrogen in the Mixed Herbage of Permanent Grass-land at Rothamsted.

Plots.	Conditions of Manuring.	Average Produce per acre per annum, 20 years, 1856-1875, according to Mean per cent. at 6 periods 1862, '67 '71, '72, '74, '75.			Average Nitrogen per Acre per annum.		
		Gramineæ.	Leguminosæ.	Other Orders.	10 years 1856-1865	10 years 1866-1875	20 years 1856-1875
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3	Unmanured	1635	219	529	35·1	30·9	33·0
4-1	Superphosphate[1]...	1671	149	673	35·7	31·6	33·6
8	Complex Min. Man.[2]	2442	296	639	54·4	38·5	46·5
7	Complex Min. Man.[3]	2579	806	573	55·2	58·0	56·6

[1] Mean of 4 Separations only, namely 1862, 1867, 1872, and 1875.
[2] Including potash 6 years, 1856-1861 ; without potash, 14 years 1862-1875.
[3] Including potash 20 years, 1856-1875.

The quantities of nitrogen yielded are calculated from the results of actual determinations of the nitrogen in the mixed produce of the respective plots; but the estimates of the quantity of the produce referable to the different natural orders must be taken as only giving a general indication or an approximation to the truth; for, whilst the amount of the total mixed produce is the average of that of the twenty years, the amount of it referred to the different orders is calculated upon their percentage determined in six years only, four of which are among the last five, and the fluctuation according to season is in some cases very considerable, whilst in others there is a progression in the changes, which render an accurate estimate of the average botanical composition of the herbage over the whole period impossible. The figures do, however, undoubtedly represent the truth sufficiently nearly for our present purpose. But before referring to the yield of nitrogen, it may be remarked, in passing, how much greater is the increase of gramineous produce by the use of purely mineral manures in this mixed herbage than in the case of gramineous crops grown separately. The interesting question arises, how far the result is due to the direct action of the mineral manures in enabling the grasses to form much more stem and seed—that is, the better to mature—which, as a matter of fact, they are found to do? or how far the increased growth is to be explained by an increased accumulation of combined nitrogen available for the grasses in the upper layers of the soil, as the result of the increased growth of the leguminosæ induced by the potash manure, as already illustrated by the results obtained in alternating clover and barley, and in an actual course of rotation?

Referring to the yield of nitrogen, it is seen that, without manure, it has diminished during the last as compared with the first 10 years; but that the average is 33 lbs. per acre, per annum, or considerably more than with a gramineous crop grown separately.

With super-phosphate of lime alone, the yield of nitrogen over the first 10, the second 10, and the 20 years, is very nearly the same as without manure. It is slightly higher, as also is the total amount of produce; but whilst the quantity contributed by gramineous species is rather more, that yielded by leguminous species is less, and that by species belonging to other orders more than without manure.

With super-phosphate of lime, and sulphates of potash, soda, and magnesia, during the first 6 years, but no potash during the last 14 years (plot 8), the amount of both gramineous and leguminous herbage is very much increased; and that of the leguminous produce

was especially so during the earlier years. The result is a yield of 54·4 lbs. of nitrogen per acre, per annum, over the first 10 years, of only 38·5 lbs. over the second 10 years, and of 46·5 lbs. over the 20 years.

With the complex mineral manure, including potash each year throughout the period of twenty years (plot 7), leguminous species contribute about one-fifth of the whole produce, or very much more than in either of the other cases. The result is an annual yield of 55·2 lbs. of nitrogen over the first 10 years; of even slightly more, or 58 lbs., over the second 10 years; and of 56·6 lbs. over the whole period of 20 years—that is, considerably more than twice as much as would be yielded by a gramineous crop grown separately on arable land. It may here be observed that, whilst in the case of each of the first three plots referred to, the produce of the mixed herbage diminished over the second as compared with the first 10 years, that of plot 7, with the potash manure, and so much leguminous herbage, increased slightly over the second compared with the first 10 years. Finally, it may be remarked on this point, how comparatively uniform is the average yield of produce by all other species other than the gramineous and the leguminous on the four very differently manured plots.

Here again, then, the results relating to the growth of species of many different natural orders growing together, like those relating to the growth of individual species grown separately, show that those of the leguminous family, and probably those of various other orders also, have the capacity of assimilating much more nitrogen over a given area than species of the order gramineæ.

Assuming for the sake of argument that the yield of nitrogen by the gramineæ grown separately may be explained, as already suggested, by reference to the amount of combined nitrogen acquired from the measured aqueous deposits from the atmosphere, together with that condensed within the pores of the soil, and that derived from previous accumulations within it, the question arises, can the greatly increased yield by other plants be so accounted for? or, if not, how otherwise may it be explained? We will endeavour to weigh the evidence bearing upon this point.

It so happens that the plants which do gather, or which have been supposed to gather nitrogen more readily than the gramineæ, have obviously a different character of foliage; as, for instance, the "root-crops"—turnips and the like; and the leguminous crops—beans, peas, clover, &c. An obvious explanation, therefore, which will be found in books of authority, is that these so distinguished "broad-leaved

plants" have the power of taking up nitrogen in some form from the atmosphere, in a degree, or in a manner, not possessed by the narrow-leaved gramineous plants. It is true that Adolph Mayer in Germany, and Schlösing in France, have experimentally shown that plants can take up nitrogen by their leaves from ammonia supplied to them in the ambient atmosphere. But I think I am right in saying that the conclusion of both of these experimenters is that this action takes place in a very immaterial degree in natural vegetation.

In reference to this subject, I may observe that the results of the determinations of the ammonia in the atmosphere by different experimenters, and in different localities, vary very greatly; and it may be concluded that a shower of rain will wash out much of it. According to M. Schlösing's statement of the results of his recent determinations of the ammonia in the air of Paris (Compt. Rend. lxxxi. p. 1252 et seq.), it ranges from one part in about 12,500,000, to one part in about 260,000,000 of air by weight. If, for the purpose of illustration, we assume that, on the average, the ambient atmosphere in the open country—in Europe, at any rate—will contain one part of ammonia in about 60,000,000 of air, or one part of nitrogen as ammonia in about 50,000,000 of air, the atmosphere would thus contain more than 8,000 times less nitrogen as ammonia than carbon as carbonic acid. But cereal crops contain 1 part of nitrogen to about 30 of carbon, and leguminous crops, 1 of nitrogen to 15, or fewer, of carbon. On these assumptions, the ambient atmosphere would contain a proportion of nitrogen as ammonia, to carbon as carbonic acid, about 267 times less than that of nitrogen to carbon in cereal produce, and about 534 times (or more) less than that in leguminous produce. It is true that water would absorb very much more nitrogen as ammonia, or dissolve very much more as carbonate or bi-carbonate of ammonia, than it would of carbon as carbonic acid under equal circumstances. Hence, there would appear to be a compensating quality for the small actual and relative amount of nitrogen as ammonia in the atmosphere, in the greater solubility or absorbability of the compounds in which nitrogen exists, than of the carbonic acid in which the carbon is presented. Further, it can hardly be to a greater mere extent of leaf or above-ground surface that the result could be attributed. Thus, though a bean and a wheat crop may yield about equal amounts of dry matter per acre, the bean produce would contain from two to three times more nitrogen, and approximate measurements show that a wheat plant offers a greater external superficies in relation to a given

weight of dry substance than a bean plant, and greater still therefore in relation to a given amount of nitrogen fixed. If, then, the bean can in some way take up more nitrogen from the atmosphere than the wheat, the result must be due to character and function, rather than to mere extent of surface above ground. It may, however, be observed that, as a rule, even those of the leguminous crops which are grown for their ripened seed, maintain their green and succulent surface over a more extended period of the season of active growth than do the gramineous corn crops.

It may safely be asserted, then, that neither direct experimental evidence, nor a consideration of the chemistry and the physics of the subject, would lead to the conclusion that the plants which assimilate more nitrogen over a given area than others, do so by virtue of a greater power of absorbing by their leaves combined nitrogen from the atmosphere in the form of ammonia. And here it may be said, in passing, that the argument would be still stronger against the supposition that nitric acid in the atmosphere supplies directly to the leaves of plants any important amount of the nitrogen they assimilate.

But apart from the more purely scientific considerations bearing upon the question, we believe that our statistics of nitrogen-production are themselves sufficient to justify the conclusion that, at any rate, the "broad-leaved" *root-crops*, turnips and the like, to which the function has with the most confidence been attributed, do not take up any important proportion of their nitrogen by their leaves from combined nitrogen in the atmosphere. Thus, it has already been shown, that the yield of nitrogen in these crops, even with the aid of complex mineral manures, was in the later years reduced to a lower point than that in any other crop; the percentage of nitrogen in the upper layers of the soil was also reduced to a lower point than with any other crop. The evidence of this kind is, however, admittedly not so conclusive in regard especially to plants of the leguminous family.

But as about four-fifths of the atmosphere which surrounds the leaves of plants consist of free nitrogen, why should not this be a source to them of the nitrogen they require? To assume that it is so, is such an obvious and easy way out of so many difficulties, that this assumption has from time to time been freely made, and much experimental investigation has been undertaken on the point, with the most conflicting results. It is now nearly 40 years ago since Boussingault showed that there was a greater assimilation of nitrogen

over a given area in a rotation of crops than he could well account for; and almost from that time to this he has been occupied with investigations of very various kinds, sometimes on the atmosphere, sometimes on meteoric waters, sometimes on plants, and sometimes on soils, the main object of which has obviously been to throw light on the question of the sources of the nitrogen of vegetation. And almost for as long a period as Boussingault, Mr. Lawes and myself have devoted much thought and investigation to the same end.

On this point, of whether or not plants assimilate the free nitrogen of the atmosphere, leaving out of view, for lack of time and space, the experiments and conclusions of several others who have worked on the subject on a less comprehensive scale, I will first briefly direct attention to the most comprehensive series of experiments, the results of which led the author to conclude that the free nitrogen of the atmosphere is taken up and assimilated by the leaves of plants.

During the years 1849, 1850, 1851, 1852, 1854, 1855, and 1856, M. G. Ville, of Paris, made numerous experiments on this subject. His plants were generally enclosed in a glass case, and his soils consisted of washed and ignited sand, sand and brick, or sand and charcoal. They were sometimes supplied with a current of unwashed air, sometimes with a current of washed air, and they were sometimes in free air; sometimes a known quantity of ammonia was supplied to the air of the apparatus, and sometimes known quantities of nitrate were supplied to the soil. Lastly a great variety of plants was experimented upon. M. G. Ville's results are summarised in Table V. below.

TABLE V.

Summary of the Results of M. G. VILLE'S *Experiments, to determine whether Plants assimilate free Nitrogen.*

Plants.	Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.
	In Seed, and Air; and Manure, if any.	In Products (Plants only).	Gain or Loss.	
1849: *Current of unwashed air supplying* 0·001 *grammes Nitrogen as Ammonia.*[1]				
Cress...	0·0260	0·1470	0·1210	5·6
Large Lupins ...	0·0640	0·0640	0·0000	1·0
Small Lupins ...	0·0640	0·0470	−0·0170	0·7
	0·1550	0·2580	0·1030	1·7

[1] Recherches Expérimentales sur la Végétation, par M. GEORGES VILLE. Paris, 1853.

TABLE V.—*continued.*

Plants.	Nitrogen—Grammes. In Seed, and Air; and Manure, if any.	Nitrogen—Grammes. In Products (Plants only).	Nitrogen—Grammes. Gain or Loss.	Nitrogen in Products to 1 Supplied.
1850: *Current of unwashed air supplying* 0·0017 *grammes Nitrogen as Ammonia.*[1]				
Colza (plants) ...	0·0260	1·0700	1·0440	41·1
Wheat	0·0160	0·0310	0·0150	1·9
Rye	0·0130	0·0370	0·0240	2·8
Maize	0·0290	0·1280	0·0990	4.4
	0·0857	1·2660	1·1803	14·8
1851: *Current of washed air.*[1]				
Sunflower... ...	0·0050	0·1570	0·1520	31·4
Tobacco	0·0040	0·1750	0·1710	43·7
Tobacco	0·0040	0·1620	0·1580	40·5
1852: *Current of washed air.*[1]				
Autumn Colza...	0·0480	0·2260	0·1780	4·7
Spring Wheat...	0·0290	0·0650	0·0360	2·2
Sunflower... ...	0·0160	0·4080	0·3920	25·5
Summer Colza...	0·1730	0·5950	0·4220	3·4
Summer Colza...	0·1050	0·7010	0·5960	6·7
1854: *Current of washed air (under superintendence of a Commission*				
Cress...	0·0099	0·0097	−0·0002	1·0
Cress...	0·0038	0·0530	0·0492	13·9
Cress...	0·0039	0·0110	0·0071	2·8
1854: *Current of washed air (closed, under superintendence of a Commission).*[2]				
Cress...	0·0063	0·0350	0·0287	5·6
1855 and 1856: *In free air, with* 0·5 *grammes Nitre* = 0·069 *Nitrogen*				
Colza...	0·0700	0.0700	0·0000	1·0
Colza...	0·0700	0·0660	−0·0040	0·9
Colza...	0·0700	0·0680	−0·0020	1·0
1855 *and* 1856: *In free air, with* 1 *gramme Nitre* = 0·138 *Nitrogen.*[3]				
Colza...	0·1400	0·1970	0·0570	1·41
Colza...	0·1400	0·3740	0·2340	2·67
Colza...	0·1400	0·2160	0·0760	1·54
Colza...	0·1400	0·2500	0·1100	1·79

[1] Recherches Expérimentales sur la Végétation, par M. GEORGES VILLE. Paris, 1853.
[2] Compt. rend., 1855. [3] Recherches Expérimentales sur la Végétation, 1857.

TABLE V.—*continued.*

Plants.	Nitrogen—Grammes: In Seed, and Air; and Manure, if any.	Nitrogen—Grammes: In Products (Plants only).	Nitrogen—Grammes: Gain or Loss.	Nitrogen in Products to 1 Supplied.
1856: *In free air, with* 0·792 *grammes Nitre* = 0·110 *Nitrogen.*[1]				
Wheat	0·1260	0·2180	0·0920	1·7
Wheat	0·1260	0·2240	0·0980	1·8
1855: *In free air, with* 1·72 *grammes Nitre* = 0·238 *Nitrogen.*[1]				
Wheat	0·2590	0·3080	0·0490	1·2
1856: *In free air, with* 1·765 *grammes Nitre* = 0·244 *Nitrogen.*[1]				
Wheat	0·2650	0·2170	−0·0480	0·8
Wheat	0·2650	0·3500	+0·0850	1·3

We have already discussed the results of M. G. Ville, as well as those of others, in a paper published in the *Philosophical Transactions* for 1859, and in a somewhat condensed form in the *Journal of the Chemical Society*, vol. xvi. 1863; and we can only very briefly refer to them in this place. The column of actual gain or loss of nitrogen is seen to show in one case a gain of more than 1 gram of nitrogen; the amount of it in the products being more than 41 fold that supplied as combined nitrogen in the seed, and air. This result was obtained with colza. Those obtained with wheat, rye, or maize, showed very much less of both actual and proportional gain. Experiments with sunflower and tobacco showed a less actual gain than that with colza; but still it amounted in one case, with sunflower, to more than 30, and in two, with tobacco, to more than 40 fold of that supplied. In M. G. Ville's later experiments (as a glance down the last two columns in the table will show), although he still had generally some gain, it was usually both actually and in proportion to the quantity supplied considerably less than in his earlier ones.

M. G. Ville attributed the gain, in some cases, to the large leaf-surface. In explanation of the assimilation of free nitrogen by plants, he calls attention to the fact that nascent hydrogen is said to give ammonia, and nascent oxygen nitric acid, with free nitrogen, and he asks—Why should not the nitrogen in the juices of the plant

[1] Recherches Expérimentales sur la Végétation, 1857.

combine with the nascent carbon and oxygen in the leaves? He refers to the supposition of M. De Luca, that the nitrogen of the air combines with the nascent oxygen given off by the leaves of plants, and to the fact that the juice of some plants (mushrooms) has been observed to ozonize the oxygen of the air, and he asks—Is it not probable, then, that the nitrogen dissolved in the juices will submit to the action of the ozonized oxygen with which it is mixed, when we bear in mind that the juices contain alkalies, and penetrate tissues, the porosity of which exceeds that of spongy platinum?

The experiments of M. Boussingault, and of ourselves, on the other hand, have not given an affirmative answer to the question whether plants, by their leaves, take up and assimilate the free nitrogen of the air.

M. Boussingault commenced his experiments on this subject in 1837, and Table VI., which follows, summarises his results, obtained at intervals from that date up to 1858.

TABLE VI.

Summary of the Results of M. BOUSSINGAULT'S *Experiments, to determine whether Plants assimilate free Nitrogen.*

Plants.	Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.
	In Seed, or Plants; and Manure, if any.	In Products.[1]	Gain or Loss.	
1837: *Burnt soil, distilled water, free air, in closed summer-house.*[2]				
Trefoil	0·1100	0·1200	+0·0100	1·09
Trefoil	0·1140	0·1560	+0·0420	1·37
Wheat	0·0430	0·0400	−0·0030	0·93
Wheat	0·0570	0·0600	+0·0030	1·05
1838: *Conditions as in* 1837.[3]				
Peas	0·0460	0·1010	+0·0550	2·20
Trefoil (Plants) .	0·0330	0·0560	+0·0230	1·70
Oats (Plants) ...	0·0590	0·0530	−0·0060	0·90
1851 *and* '52: *Washed and ignited pumice with ashes, distilled water, limited air, under glass shade, with Carbonic Acid.*[4]				
Haricot, 1851 ...	0·0349	0·0340	−0·0009	0·97
Oats, 1851 ...	0·0078	0·0067	−0·0011	0·86
Haricot, 1852 ...	0·0210	0·0189	−0·0021	0·90
Haricot, 1852 ...	0·0245	0·0226	−0·0019	0·92
Oats, 1852 ...	0·0031	0·0030	−0·0001	0·97

[1] In the case of the 1837 and 1838 experiments, the nitrogen "In Products" seems to have included only that in the plants; in the other cases that in plants and soil, or plants, soil, and pot. [2] Ann. Ch. Phys., [2] lxvii. (1838). [3] Ibid. lxix. [4] Ann. Ch. Phys., [3] xli. (1854).

TABLE VI.—*continued.*

Plants.	Nitrogen—Grammes. In Seed, or Plants; and Manure, if any.	Nitrogen—Grammes. In Products.[1]	Nitrogen—Grammes. Gain or Loss.	Nitrogen in Products to 1 Supplied.
1853: *Prepared pumice, or burnt brick, with ashes; distilled water, limited air, in glass globe, with Carbonic Acid.*[2]				
White Lupin	0·0480	0·0483	+ 0·0003	1·01
White Lupin	0·1282	0·1246	− 0·0036	0·97
White Lupin	0·0349	0·0339	− 0·0010	0·97
White Lupin	0·0200	0·0204	+ 0·0004	1·02
White Lupin	0·0399	0·0397	− 0·0002	1·00
Dwarf Haricot ...	0·0354	0·0360	+ 0·0006	1·02
Dwarf Haricot ...	0·0298	0·0277	− 0·0021	0·93
Garden Cress	0·0013	0·0013	0·0000	1·00
White Lupin	0·1827	0·1697	− 0·0130	0·93
1854: *Prepared pumice with ashes, distilled water, current of washed air, and Carbonic Acid, in glazed case.*[3]				
Lupin	0·0196	0·0187	− 0·0009	0·95
Dwarf Haricot ...	0·0322	0·0325	+ 0·0003	1·01
Dwarf Haricot ...	0·0335	0·0341	+ 0·0006	1·02
Dwarf Haricot ...	0·0339	0·0329	− 0·0010	0·97
Dwarf Haricot ...	0·0676	0·0666	− 0·0010	0·99
Lupin	0·0180	0·0334	− 0·0021	0·94
Lupin	0·0175			
Cress...	0·0046	0·0052	+ 0·0006	1·13
1851, '52, '53, *and* '54: *Prepared soil, or pumice with ashes; distilled water, free air, under glazed case.*[3]				
Haricot (dwarf), 1851	0·0349	0·0380	+ 0·0031	1·09
Haricot, 1852	0·0213	0·0238	+ 0·0025	1·12
Haricot, 1853	0·0293	0·0270	− 0·0023	0·92
Haricot (dwarf), 1854	0·0318	0·0350	+ 0·0032	1·10
Lupin (white), 1853...	0·0214	0·0256	+ 0·0042	1·20
Lupin, 1854	0·0199	0·0229	+ 0·0030	1·15
Lupin, 1854	0·0367	0·0387	+ 0·0020	1·05
Oats, 1852	0·0031	0·0041	+ 0·0010	1·32
Wheat, 1853	0·0064	0·0075	+ 0·0011	1·17
Garden Cress, 1854...	0·0259	0·0272	+ 0·0013	1·05
1858: *Nitrate of Potash as Manure.*[4]				
Helianthus... ...	0·0144[5]	0·0130	− 0·0014	0·90
Helianthus... ...	0·0255[5]	0·0245	− 0·0010	0·96

[1] In all cases the nitrogen "In Products" included that in plants and soil, or plants, soil, and pot. [2] Ann. Ch. Phys., [3] xli. (1854). [3] Ann. Ch. Phys., Sér. [3] xliii. (1855). [4] Compt. rend., xlvii. (1858). [5] Nitrogen in Seed and Nitrate.

M. Boussingault's soils consisted of burnt soil, washed and ignited pumice, or burnt brick ; his experiments were sometimes in free air, sometimes in a closed vessel with limited air, sometimes with a current of washed air, and sometimes in free air, but under a glass case. When the plants were enclosed, a supply of carbonic acid was provided, and in a few cases known quantities of nitre were supplied as manure.

The last two columns of the Table (VI.) show the actual and proportional gain of nitrogen in M. Boussingault's experiments. It will be observed that in his earliest experiments, those in free air, in a summer house, the leguminous plants, trefoil and peas, did indicate a notable gain of nitrogen ; but in all his subsequent experiments there was generally either a slight loss, or, if a gain, it was represented in only fractions, or low units, of milligrams. After twenty years of varied and laborious investigation of the subject, M. Boussingault concluded that plants have not the power of taking up and assimilating the free nitrogen of the atmosphere.

Our own experiments on this subject were commenced in 1857, and the late Dr. Pugh, of the Pennsylvania State Agricultural College, devoted between two and three years to the investigation at Rothamsted. Mr. Lawes has contributed one complete set of the apparatus employed to this Exhibition. The arrangement, and the results obtained up to that date, are fully described in the papers already referred to, published in the *Philosophical Transactions* for 1859, and in the *Journal of the Chemical Society* in 1863. They may be briefly described as follows :—

The soils used were ignited, washed, and re-ignited, pumice, or soil. The specially made pots were ignited before use, and cooled over sulphuric acid under cover. The pots, with their plants, were enclosed under a glass shade resting in the groove of a specially made hard-baked glazed stone-ware lute-vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soils ; and there was an outlet at the bottom of the lute-vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure. A stream of water being allowed to flow into a large stone-ware Wolff's bottle (otherwise empty), air passed from it through two small glass Wolff's bottles containing sulphuric acid, then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Wolff's bottle containing a saturated solution of ignited carbonate of soda ; and,

after being so washed, the air enters the glass shade, from which it passes, by the exit tube, through an eight bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air is prevented. Carbonic acid is supplied as occasion may require, by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas being passed through one of the bottles of sulphuric acid, through the long tube, and through the carbonate of soda solution, before entering the shade.

It will be observed that, by the arrangement described, the washed air is forced, not aspirated, through the shade, and the pressure being thus the greater within the vessel, the danger of leakage of unwashed air from without inwards is lessened. In 1857, twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute-vessels, and shades; in 1859 six, and in 1860 also six. The whole were arranged, side by side, in the open air, on stands of brick-work, as described in the papers referred to, and shown in the apparatus exhibited. Drawings of some of the plants grown were also exhibited, and the published results are summarised in Table VII.

TABLE VII.

Summary of the Results of Experiments made at Rothamsted, to determine whether Plants assimilate Free Nitrogen.

			Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.
			In Seed, and Manure if any.	In Plants, Pot and Soil.	Gain or Loss.	
With NO *combined Nitrogen supplied beyond that in the seed sown.*						
Gramineæ.	1857.	Wheat	0·0080	0·0072	−0·0008	0·90
		Barley	0·0056	0·0072	+0·0016	1·29
		Barley	0·0056	0·0082	+0·0026	1·46
	1858.	Wheat	0·0078	0·0081	+0·0003	1·04
		Barley	0·0057	0·0058	+0·0001	1·02
		Oats	0·0063	0·0056	−0·0007	0·89
	1858. A[1]	Wheat	0·0078	0·0078	0·0000	1·00
		Oats	0·0064	0·0063	−0·0001	0·98
Leguminosæ.	1857.	Beans	0·0796	0·0791	−0·0005	0·99
	1858.	Beans	0·0750	0·0757	+0·0007	1·01
		Peas	0·0188	0·0167	−0·0021	0·89
Other Plants.	1858.	Buck Wheat	0·0200	0·0182	−0·0018	0·91

[1] These experiments were conducted in the apparatus of M. G. Ville.

TABLE VII.—*continued.*

			Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.
			In Seed, and Manure if any.	In Plants, Pot and Soil.	Gain or Loss.	
WITH *combined Nitrogen supplied beyond that in the seed sown.*						
Gramineæ.	1857.	Wheat	0·0329	0·0383	+0·0054	1·16
	1857.	Wheat	0·0329	0·0331	+0·0002	1·01
	1857.	Barley	0·0326	0·0328	+0·0002	1·01
	1857.	Barley	0·0268	0·0337	+0·0069	1·25
	1858.	Wheat	0·0548	0·0536	−0·0012	0·98
	1858.	Barley	0·0496	0·0464	−0·0032	0·94
	1858.	Oats	0·0312	0·0216	−0·0096	0·69
	1858. A[1]	Wheat	0·0268	0·0274	+0·0006	1·02
	1858. A[1]	Barley	0·0257	0·0242	−0·0015	0·94
	1858. A[1]	Oats	0·0260	0·0198	−0·0062	0·76
Leguminosæ.	1858.	Peas	0·0227	0·0211	−0·0016	0·93
	1858.	Clover	0·0712	0·0665	−0·0047	0·93
	1858. A[1]	Beans	0·0711	0·0655	−0·0056	0·92
Other Plants.	1858.	Buck Wheat	0·0308	0·0292	−0·0016	0·95

The upper part of the table shows the results obtained in 1857 and 1858 in the experiments in which no combined nitrogen was supplied beyond that contained in the seed sown. The drawings show how extremely restricted was the growth under these conditions, and the figures in the table show that neither with the gramineæ, the leguminosæ, nor with buckwheat, was there in any case a gain of three milligrams of nitrogen indicated. In most cases there was much less gain than this, or a slight loss. There was in fact nothing in these results to lead to the conclusion that either the gramineæ, the leguminosæ, or the buckwheat had assimilated free nitrogen.

The lower part of the table shows the results obtained in 1857 and 1858, in the experiments in which the plants were supplied with known quantities of combined nitrogen in the form of a solution of ammonium sulphate applied to the soil. The gains or losses range a little higher

[1] These experiments were conducted in the apparatus of M. G. Ville.

in these experiments, in which larger quantities of nitrogen were involved, but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the gramineæ, whilst there is in each case a loss with the leguminosæ, and with the buckwheat. On this point it should be stated that the growth was far more healthy with the gramineæ than with the leguminosæ, which are even in the open fields very susceptible to the vicissitudes of heat and moisture, and were found to be extremely so when enclosed under glass shades. It might be objected, therefore, that the negative results with the leguminosæ are not so conclusive as those with the gramineæ. However this may be, taking the results as they stand, there is nothing whatever in them to lead to the conclusion that either the gramineæ or the leguminosæ can take up and assimilate the free nitrogen of the atmosphere. We, indeed, do not hesitate to conclude from our own experiments, as Boussingault did from his, that the evidence is strongly against the supposition that plants can so avail themselves of the free nitrogen of the atmosphere.

Independently of the action suggested as possible by M. G. Ville, that is between free nitrogen and nascent or ozonized oxygen within the plant itself, it has been supposed that the free nitrogen of the atmosphere may unite with the nascent oxygen, or ozone, as the case may be, evolved by the plant, and so yield nitric acid. In our papers above referred to we have given reasons for supposing that such actions are not likely to take place; but whether they do or do not, it is at any rate certain than in our own experiments we have not been able to persuade plants to avail themselves of this happy faculty of producing their own nitrogenous food. With regard to the action supposed possibly to take place externally to the plant itself, if it were in any material degree operative, we should expect some, at least, of the resulting combined nitrogen to be collected in the aqueous deposits from the atmosphere; but we have seen how inadequate is the amount of combined nitrogen in those deposits to account for the yield of nitrogen, even of the gramineæ, and still less can it satisfactorily explain the yield in the leguminosæ and other plants.

But if the plant itself cannot either assimilate free nitrogen, or effect its combination so as to bring it into a state for its use, may not such combination take place under the influence of the soil?

More than 30 years ago, Mulder argued that in the last stages of decomposition of organic matter in the soil, hydrogen was evolved,

and that this nascent hydrogen combined with the free nitrogen of the air, and so formed ammonia.

A few years ago Dehérain substantially revived this view. He maintained that at a certain depth the air of the soil is poor in, or destitute of, oxygen ; that hydrogen is evolved from the decomposing organic matter ; that it unites with free nitrogen to form ammonia ; and, that so, combined nitrogen increases in the soil in spite of the growth and removal of crops. This view he supports by some laboratory experiments.

It is obvious that if the reality of this action in soils were unquestionably established, it would greatly aid the solution of the question we are discussing. There are, indeed, results of others on record which would seem to lend it probability.

Thus, Bretschneider found, on exposure of a mixture of humic acid and quartz sand to the air for a whole year, under conditions in which it was protected from rain and insects, that there was a gain of combined nitrogen which would represent an increase of more than 40 lbs. per acre.

Again, Boussingault exposed a moist garden soil for three months, and found a small gain of nitrogen. His explanation, was, however, different. He supposed it possible that ozone might be evolved in the oxidation of organic matter in the soil, and unite with free nitrogen, and so nitric acid be produced, and the soil gain in combined nitrogen. In other experiments Boussingault put mixtures of vegetable mould and pure sand in small quantities in large glass vessels which he perfectly closed and preserved in a dark cellar for a whole year. At the end ot that period oxidation of organic matter had taken place, nitric acid was formed, but there was upon the whole a small loss of combined nitrogen. Lastly in regard to Boussingault's results bearing upon this point, it has already been shown that in all of his experiments with plants in which his soils consisted of ignited pumice, ignited brick, or the like, without organic matter, he found no gain of combined nitrogen in soil and plant. In 1858 and 1859, however, he made a number of experiments on growth, in which part of the soil consisted of rich garden mould; and in two cases with lupins growing in confined air, and in one with haricot growing in free air, his results showed a notable gain of combined nitrogen ; and although the quantity of garden mould employed was not the same in the three cases, the gain of nitrogen was approximately in proportion to the amount of soil used. The gain was, indeed, in the soil rather than in the plant.

In the other experiments, however, either much less, or no gain was indicated.

Much more recently, Boussingault has published the results of experiments which showed that when a garden soil was confined for about 11 years in closed glass vessels in an atmosphere containing oxygen, the free nitrogen did not serve for the formation of nitric acid within it; but, on the contrary, the soil lost a portion of its combined nitrogen.

Since the delivery of this lecture, M. Berthelot (Compt. Rend, T. lxxxii. p. 1,357) has stated that in experiments in which he exposed moistened cellulose to an electric current in an atmosphere of nitrogen, he found nitrogen taken up, and a fixed nitrogenous body formed. Referring to the last mentioned experiments of M. Boussingault, and his conclusions from them, M. Berthelot objects that the soils being in closed glass vessels, the intervention of atmospheric electricity was excluded, and the conditions of the experiments were, so far, unlike those of a natural soil.

Being very desirous to know the present opinion of M. Boussingault on the various points involved in this important question of the sources of the nitrogen of vegetation, I wrote to him shortly after undertaking to give this address, and asked whether he would be kind enough to favour me with a statement of his views on certain points. Unfortunately his reply did not reach me until after the delivery of the lecture; but, with his permission, I am now enabled to contribute a very valuable addition to the discussion in the form of a translation of the more essential parts of M. Boussingault's letter. He says :—

"(1.) In confined stagnant air, or in air moving through a closed apparatus, after previous purification, but still containing carbonic acid, plants growing in a soil destitute of nitrogenous manure, but containing the mineral substances indispensable for the vegetable organism, do not assimilate the nitrogen which is in a gaseous state in the atmosphere."

"(2.) In the open air, in a soil destitute of nitrogenous manure, but containing the mineral substances necessary for the vegetable organism, plants acquire very minute quantities of nitrogen, arising, no doubt, from minute proportions of fertilising nitrogenous ingredients carried by the air, ammoniacal vapours, and dust, always containing alkaline or earthy nitrates."

"(3.) In confined stagnant air, or in air renewed in a closed apparatus, a plant growing in a soil containing a nitrogenous manure, and

mineral substances necessary for the vegetable organism, or in fertile vegetable earth, does not assimilate free nitrogen."

"(4.) In field culture, where dung is applied in ordinary quantities, analysis shows that there is more nitrogen in the crops than was contained in the manure applied."

"This excess of nitrogen comes from the atmosphere, and from the soil."

"(A.) From the atmosphere, because it furnishes ammonia in the form of carbonate, nitrates or nitrites, and various kinds of dust. Theodore de Saussure was the first to demonstrate the presence of ammonia in the air, and consequently in meteoric waters. Liebig exaggerated the influence of this ammonia on vegetation, since he went so far as to deny the utility of the nitrogen which forms a part of farm-yard manure. This influence is, nevertheless, real, and comprised within limits, which have quite recently been indicated in the remarkable investigations of M. Schlösing."

"(B.) From the soil, which, besides furnishing the crops with mineral alkaline substances, provides them with nitrogen, by ammonia, and by nitrates, which are formed in the soil at the expense of the nitrogenous matters contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilising by the effect of time. If we take into account their immensity, the deposits of the last geological periods must be considered as an inexhaustible reserve of fertilising agents. Forests, prairies, and some vineyards, have really no other manures than what are furnished by the atmosphere, and by the soil. Since the basis of all cultivated land contains materials capable of giving rise to nitrogenous combinations, and to mineral substances, assimilable by plants, it is not necessary to suppose that in a system of cultivation the excess of nitrogen found in the crops is derived from the free nitrogen of the atmosphere. As for the absorption of the gaseous nitrogen of the air by vegetable earth, I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off, as you have observed in conjunction with Mr. Lawes, as Reiset has shown in the case of dung, as M. Schlösing and I have proved in our researches on nitrification."

"If there is one fact perfectly demonstrated in physiology, it is this of the non-assimilation of free nitrogen by plants; and I may add by plants of an inferior order, such as mycoderms, and mushrooms."

Numerous experiments of Schlösing indicate a similar result to that last quoted of Boussingault. He selected a soil rich in humus, containing about 16 per cent. of moisture, and 0·263 per cent. of combined nitrogen. Known quantities of it were placed in large wide glass tubes, and during a period of about four months, he aspirated over them air containing respectively from 1·5 to 21 per cent. of oxygen. He determined the carbonic acid in the air passing off, and the nitric acid in the soil before and after the experiment. He found that both the combustion of the organic matter, and the formation of nitric acid, were very considerable, even with the lowest proportion of oxygen in the air; but that the formation of the nitric acid in particular was very much the greater, the larger the proportion of oxygen in the air.

In a second set of experiments, he used the soil in a moister condition; and instead of the experiment in which the air contained only 1·5 of oxygen, he employed pure nitrogen; and the experiments extended over a period of about six months. In the case in which the aspirated air contained no oxygen, the whole of the nitric acid previously existing in the soil disappeared; but in the other cases there was a considerable formation of nitric acid.

In a third set of experiments, Schlösing determined the nitric acid in the soils, and added known quantities of potassium nitrate in a dilute solution. The mixture was enclosed in a flask of several times the capacity of the volume of soil. At the conclusion of the experiment only traces, if any, of gas containing hydrogen and carbon were present in the air of the vessel. The amount of ammonia in the soil increased considerably, but in only small proportion to that which the nitric acid would yield. At the end of the first experiment more potassium nitrate was added, and an atmosphere of known volume and composition supplied. At the conclusion of this experiment the soil contained no nitric acid; the amount of ammonia was increased, but again in only small proportion to the amount which the nitrate would yield. There was indeed a loss of total nitrogen in the soil.

Schlösing concludes that the combustion of organic matter in the soil is accompanied by a loss of nitrogen; that the combustion may be at the cost of the air as in the experiment of Boussingault, or at the cost of nitrates, of ferric oxide, or of the oxygen of the organic matter, as in his own experiments.

It will be seen that on this important point of whether or not the soil

may acquire combined nitrogen either in the form of ammonia by the combination of free nitrogen with nascent hydrogen evolved in the decomposition of organic matter in defect of oxygen, or in the form of nitric acid by the oxidation of free nitrogen, the evidence is, to say the least, conflicting. The more recent results of Boussingault, and those of Schlösing, would, however, indicate a greater probability of a loss of combined nitrogen, and evolution of free nitrogen.

Judging of the probabilities by reference to some of the results of our own investigations, we think that they are rather against than in favour of the supposition that there is any material gain of the kind assumed by Mulder and Dehérain. It may be well, however, briefly to call attention to some few facts which seem to bear upon the point, whether in favour, or otherwise, of the view in question.

The action assumed by Mulder and Dehérain, if it have place at all in soils in their natural condition, would be supposed, and is assumed by Dehérain, to occur in layers sufficiently deep to be poor in oxygen. In the lower layers of the soil there is, however, a deficiency of carbonaceous organic matter also. Again, if such formation of ammonia do take place, it is probable that some at any rate of it must be oxidated into nitric acid; a condition which, on the other hand, implies an atmosphere not poor in oxygen. Thus, numerous results of analysis of the drainage water from many of the experimental plots at Rothamsted, to which further reference will be made presently, show that nearly the whole of the combined nitrogen in the drainage collected at a depth of about 30 inches, exists as nitrates and nitrites; which, obviously, would hardly be the case if the solution passed through a considerable layer of soil, the interstices of which contained an atmosphere poor in, or destitute of, oxygen.

Again, assuming such formation of ammonia to take place in the upper layers of the soil, where there is the most organic matter, and much oxidation of it, the supposition would be that the conditions would favour oxidation rather than the formation of ammonia from free nitrogen; and the fact of the formation of a good deal of nitric acid by the oxidation of nitrogenous organic matter, or ammonia, in the surface soil, is sufficiently established.

Further, if it were to the action assumed by Mulder and Dehérain taking place in the upper layers of the soil that we owe the supplies of combined nitrogen available to leguminous and other plants which assimilate so much more of it over a given area than the gramineæ, the question may be asked—why cannot the gramineæ avail themselves

of this superficial supply? On this point it may be mentioned that, on some parts of the experimental wheat and barley fields at Rothamsted, farm-yard manure has been applied year after year, for a quarter of a century or more, in quantity containing perhaps six or seven times as much nitrogen as is removed in the increase of crop, and that thus the percentage of nitrogen in the surface soil has been more than doubled. Yet, as large a produce of barley, and a larger produce of wheat, is annually obtained by the use of very much smaller quantities of nitrogen, as ammonium-salts or nitrate. It would thus appear that the nitrogen of the farm-yard manure was only available to the cereals after its transformation into ammonia or nitric acid. Unfortunately, we are not at present able to adduce direct experimental evidence as to the condition in which the large amount of inefficient nitrogen exists in the soil, or as to whether a leguminous crop would or would not grow luxuriantly in it, but there is little doubt that it would do so. On the other hand, a good crop of clover would appear to be attainable in soil comparatively poor in nitrogen in its upper layers, and comparatively poor in organic matter also; for, in the experiments already referred to in which barley was grown after barley and after clover, the large amount of clover obtained, and nitrogen assimilated in it, was after six corn crops grown by artificial manure alone; conditions under which the amount, both of available nitrogen, and of organic matter, in the upper layers of the soil, would be supposed to be comparatively small.

The answer of Dehérain would probably be, that under the circumstances supposed, the nitrogen would be in a condition of combination not favourable for assimilation by the gramineæ; that, in fact, the ammonia formed would combine with organic acids in the soil, yielding compounds specially favourable as food for the leguminosæ. An objection to this view is, that if the accumulation in the soil by time, of nitrogen in a condition specially favourable for the leguminosæ were such as is here assumed, we should expect the amount of nitrogen in the soil, determinable by the soda-lime process, to be higher before than after the growth of a leguminous crop; whereas, on the contrary, after the growth of a leguminous crop, the amount of nitrogen so determinable in the upper layers of the soil is very appreciably increased.

The evidence in favour of the supposition that the special source of nitrogen to the leguminosæ is ammonia, or other compounds than nitric acid, in the upper layers of the soil, is then, to say the least,

inconclusive. It remains to consider whether it may not be nitric acid, either in the soil or in the subsoil?

As already said, there is abundant evidence of the formation and existence of a considerable amount of nitric acid in surface soils; even in such as contain a relatively high amount of carbonaceous and nitrogenous organic matter. For example, a soil at Rothamsted which has been under garden cultivation, and as such probably manured almost every year for centuries, has successfully grown clover every year for more than twenty years. This soil was shown by the late Dr. Pugh, and has been again recently by Mr. Warington, to contain a considerable amount of nitric acid. But such a soil would, there is no doubt, grow large crops of gramineæ also; which direct experiments show to attain great luxuriance under the influence of artificially applied nitrates. But such a rich garden soil contains an abundance of everything—mineral constituents, carbonaceous organic matter, and combined nitrogen in various forms, and thus the exact conditions which it supplies favourable to the leguminosæ cannot at once be discriminated. The fact of the comparatively little, or at least uncertain, action of directly applied nitrates on the growth of the leguminosæ, would seem to be inconsistent with the supposition that it is the nitric acid in such a surface soil that has given it its special adaptation for the growth of clover for so many years—unless, indeed, it be the case, that it is much more available to such crops when in combination with some bases than with others.

The next point to consider is, whether there are any facts in favour of the supposition that clover, and leguminous crops generally, acquire any material proportion of their nitrogen in lower layers, and in a more extended range of the soil, than the gramineæ. As an element in the discussion of this question it will be well in the first place to call attention to the effects of direct nitrogenous manures, such as ammonium-salt, or nitrates, on the growth of some of our crops.

In Table VIII. is shown the estimated amounts of carbon, yielded per acre per annum, in wheat over twenty years, in barley over twenty years, in sugar-beet over three years, and in beans over eight years; each with a complex mineral manure alone, and each with the same mineral manure and given quantities of nitrogen in addition, supplied in some cases in the form of ammonium-salts, and in others as nitrate. The gain of carbon by the use of the nitrogenous manure is also given.

TABLE VIII.

Estimated yield and gain of Carbon per acre, per annum, in experimental Crops at Rothamsted.

Manuring, Quantities per acre, per annum.	Average Carbon per acre, per annum. Actual.	Gain.
Wheat 20 *years*, 1852-1871.		
	lbs.	lbs.
Complex Mineral Manure	988	
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia	1590	602
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia	2222	1234
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate...	2500	1512
Barley 20 *years*, 1852-1871.		
Complex Mineral Manure	1138	
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia	2088	950
Sugar-Beet 3 *years*, 1871-1873.		
Complex Mineral Manure	1136	
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia	2634	1498
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate...	3081	1945
Beans 8 *years*, 1862 *and* 1864-1870.		
Complex Mineral Manure	726	
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate...	992	266

It is quite evident that in the case of the gramineous crops, wheat and barley, which contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area, and also in that of the sugar-beet, there was a greatly increased amount of carbon assimilated by the addition of nitrogenous manure alone. In the case of the wheat, there is much more effect from a given amount of nitrogen supplied as nitrate, which is always applied in the spring, than from an equal quantity as ammonium-salts, which are applied in the autumn, and are subject to winter drainage. There is also more effect from ammonium-salts applied to barley than to wheat ; the application being made for the former in the spring and for the latter in the autumn. There is again more effect from the nitrate than from the ammonium-salts when applied to sugar-beet, the application being made in both cases at the same date, in the spring.

On the other hand, the effect of the nitrogenous manure upon the highly nitrogenous bean crop is seen to be, comparatively, very insignificant.

In reference to this point it should be observed that there has been

this greatly increased assimilation of carbon in the wheat and in the barley for more than twenty years, without the addition of any carbon to the soil. It is indeed certain that, in the existing condition of our soils, the increased growth of our staple starch-yielding grains is greatly dependent on a supply of nitrogen to the soil. It is equally certain that the increased production of sugar in the gramineous sugar-cane, in the tropics, is likewise greatly dependent on the supply of nitrogen to the soil.

In reference to the great increase in the assimilation of carbon in the sugar-beet by the use of purely nitrogenous manures, it may be of interest to observe that over the three years of the experiments with sugar-beet, the increased production of sugar per acre per annum was about 20 cwts. by the use of 82 lbs. of nitrogen per acre per annum as ammonium-salts, and about 28 cwts. by the use of 82 lbs. of nitrogen as nitrate of soda.

It is, then, our characteristically starch and sugar producing crops that are the most characteristically benefited by the application of nitrogenous manures; whilst our highly nitrogenous leguminous crops are comparatively little benefited by such manures.

But now let us consider what is the proportion of the nitrogen supplied in manure that we get back in the increase of the crops that are the most specially benefited by its use.

In Table IX. is shown the amount of nitrogen recovered, and the amount not recovered, in the increase of crop for 100 supplied in manure, to wheat, and to barley, respectively; the result being in each case the average over a period of twenty years.

TABLE IX.

Nitrogen recovered, and not recovered, in the increase of produce, for 100 supplied in Manure.

Manuring, Quantities per acre, per annum.	For 100 Nitrogen in Manure. Recovered in Increase.	For 100 Nitrogen in Manure. Not Recovered in Increase.
Wheat 20 *years*, 1852-1871.		
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia	32·4	67·6
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia	32·9	67·1
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate...	45·3	54·7
Barley 20 *years*, 1852-1871.		
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia	48·1	51·9

Speaking generally, it may be said that, notwithstanding the great effects produced by the nitrogenous manures, two-thirds of the nitrogen supplied were unrecovered in the increase of crop when the ammonium-salts were applied to wheat ; the application being made in the autumn. When, however, nitrate of soda was used, which is always applied in the spring, the quantity left unrecovered was not much more than half that supplied. With barley also, the manuring for which takes place in the spring, there is again nearly half the nitrogen supplied in the manure recovered in the increase, and therefore little more than half left unrecovered.

It may be observed that, in the case of root-crops, when the supply of nitrogen is not excessive, the proportion of the nitrogen of the manure recovered in the increase may be much greater than in the case of the cereals; whilst in the case of the leguminosæ the effects of such direct application of soluble nitrogenous manures to the surface soil is comparatively so small, and so uncertain, that it would be useless to give an estimate of the amounts recovered and not recovered respectively.

But what becomes of the one-half or two-thirds of the nitrogen supplied for the increased growth of the cereals, but not recovered in the increase of crop? Dr. Frankland and Dr. Voelcker have made numerous analyses of the drainage water from the experimental wheat plots which have yielded the results above referred to, and a summary of their results is given in Table X.

TABLE X.

Nitrogen as Nitrates and Nitrites, per 100,000 *parts of Drainage Water from Plots differently manured, in the Experimental Wheat Field at Rothamsted, Wheat every year, commencing* 1844.

Manuring, Quantities per acre, per annum.	Nitrogen as Nitrates and Nitrites, per 100,000 parts Drainage Water.					
	Dr. Frankland's Results.		Dr. Voelcker's Results.		Mean.	
	Experiments.		Experiments.		Experiments.	
Farm-yard Manure	4	0·922	2	1·606	6	1·264
Without Manure	6	0·316	5	0·390	11	0·353
Complex Mineral Manure .	6	0·349	5	0·506	11	0·428
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia .	6	0·793	5	0·853	11	0·823
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia .	6	1·477	5	1·400	11	1·439
Complex Min. Man. & 123 lbs. Nitrogen, as Ammonia .	6	1·951	5	1·679	11	1·815
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate . .	5	1·039	5	1·835	10	1·437

The figures in the table conclusively show that the quantity of nitrogen as nitrates per 100,000 parts of the drainage water, increased in very direct proportion to the increase in the amount of ammonia or nitrate supplied, and it is obvious that there has been a considerable loss of the nitrogen of the manures by drainage. But as the subsoil rests upon chalk not many feet below the surface, and there is, therefore, natural drainage constantly going on, even when there is no flow from the pipes, it is impossible accurately to estimate the total amount of drainage, and therefrom the total amount of loss. Other experiments at Rothamsted, however, lead to the conclusion that, according to season, from one-quarter to nearly one-half of the annual rainfall may pass below 40 inches. Now, supposing drainage water to contain one part of nitrogen as nitrates per 100,000 parts of water, an inch of rain passing beyond the reach of the roots would carry with it 2¼ lbs. of nitrogen per acre; and it is obvious that if from seven to ten inches passed annually of that average strength, the loss would be very great. In reference to this point it is of much interest to observe, that in the Report of the River's Pollution Commission already referred to, Dr. Frankland gives a series of analyses of land drainage waters collected at Rothamsted, at depths of twenty, forty, and sixty inches, respectively; and those collected at twenty inches, almost invariably show much more nitrogen as nitric acid than those taken at either forty or sixty inches. It would thus appear to be indicated that a considerable amount of nitric acid has been arrested in the soil below the depth of twenty inches. Further, determinations of nitrogen in the soils do show some accumulation. Indeed, it would appear probable, that the whole of the nitrogen applied to the wheat as ammonium-salts or nitrate of soda, was either recovered in the increase of crop, or may be accounted for by determinable accumulation within the soil, or by loss by drainage.

In ordinary agriculture, the amounts of soluble nitrogenous manures applied would generally be much less than in some of these special experiments; and the losses by drainage would from that cause alone be proportionately less than that shown above. Much, obviously, would also depend upon the character of the soil and of the subsoil. Again, in an ordinary rotation of crops, more of the supplied nitrogen would probably be gathered up before it reached the lower layers, than in the case of a cereal crop grown year after year on the same land. It may be safely concluded, however, that whenever cereals were grown, a material proportion of the nitrogen specially applied to, or

existing in the soil, which would be available to other crops, would not be so to them ; but would in the first instance accumulate in the surface soil, and gradually pass into the lower layers in the form of nitrates, to be eventually lost by drainage if not arrested by some other crop.

The question obviously arises, whether we have not here a source of some at least of the nitrogen available to leguminous or to other plants having possession by their roots of a greater range of subsoil than the gramineæ. We have evidence enough that although wheat and barley send roots down very deep into the subsoil, and pump up moisture from the deeper layers, they nevertheless derive much of their nitrogen within the surface soil. If the leguminosæ do not so readily do so, or at any rate naturally depend more upon the nitrogen in the lower layers for a considerable proportion of that which they require, and moreover are able to avail themselves of the residue from the manuring for other crops, what is the nature of the problem that we may have to solve to elucidate this point?

By way of illustration it may be mentioned that, supposing a leguminous crop to acquire 100 lbs. of nitrogen per acre from a layer of subsoil three feet in thickness, weighing approximately 10,000,000 lbs. (exclusive of stones and water), this would represent only ·001 per cent. of nitrogen so acquired in such subsoil; 200 lbs. of nitrogen per acre so available would represent ·002 per cent., and so on. Now, even supposing that the nitrogen existed in the subsoil in such a condition as to be converted into ammonia in the process of combustion with soda-lime, the difference between one subsoil containing this, or even a larger amount of nitrogen, more than another, could not with certainty be determined by that process; for, in taking say 15 or 20 grams of the subsoil for combustion, the difference between two or more determinations could not be expected to be less than some units in the third decimal place (per cent.); that is, in fact, equal to the total amount that may be in question as between two subsoils to be compared. Further, if this available nitrogen exist in the subsoil as nitrates, it may be a question whether there would be a sufficient amount of organic matter present to insure the evolution as ammonia of the nitrogen of the nitric acid.

It has been shown, then, that there are many questions still open for investigation in regard to the relations of the surface soil to combined nitrogen; and there are obviously also equally important points to investigate in regard to the nitrogen of the subsoil, before we can hope to arrive at a satisfactory solution of some of the problems which the

consideration of the facts of vegetable production which have been adduced, suggest for enquiry. Nor are the problems still open connected with the amount, and the condition, of the mineral food of plants within the soil, either few, or without special, and independent interest. And although those relating to the nitrogen seem to call for the first attention, the marked effects, so far, of potash manures, in increasing the amount of nitrogen assimilated over a given area by the leguminosæ, seem to indicate the probability that even the difficulties connected with the sources of the nitrogen of our crops may not be solved without further knowledge as to the required conditions, or the actions, of the incombustible or mineral constituents in soils.

Our results in regard to the variations in the amount of nitrogen in the soils and subsoils of our different experimental plots, obtained by the soda-lime process, together with the results already referred to, relating to the composition of the drainage water from plots variously manured, as well as others of quite a different kind, have shown the absolute necessity for an extended investigation of the soil question by more exact methods; and Mr. Warington is about to devote, probably some years, to this enquiry at Rothamsted. It is proposed that the questions relating to the nitrogen in subsoils should be the first considered, as, if the results do throw light upon some of the points at present in doubt, a definite step in advance will be so gained; and should they not do so, the ground will thus be cleared of certain obvious suppositions, and the course of further research will be the more clearly indicated. But if the amount of nitrogen to be discriminated should prove to be represented by only units in the third decimal place per cent., say ·002 for example, it is obvious that to get as little as four milligrams involved in the analysis, 200 grams of soil would have to be operated upon. The difficulties of the problem are thus sufficiently obvious. But, by the aid of the processes of water and gas analysis which have been explained by the President in his opening address, there is little doubt that they can be overcome, at any rate so far as the nitrogen existing as nitric acid is concerned; and by the kindness of Dr. Frankland, Mr. Warington is at the present time gaining experience in the use of those methods, in the laboratory of the College of Chemistry, before entering upon this special investigation at Rothamsted.

But even supposing we arrive at a satisfactory solution of the, at present, unsettled points in regard to the sources of the nitrogen yielded in agricultural production, when, as in the experiments to

which attention has been directed, we have a soil to work upon which already contains accumulations of combined nitrogen amounting to several thousands of pounds per acre within the range of the roots of our crops, further questions in regard to the nitrogen may still be left open, namely,—to what actions a large proportion of the existing combined nitrogen may be attributed ; and what in particular is the exact source of the accumulations of it in our soils and subsoils? And here it may be observed, in passing, that determinations made at Rothamsted have shown approximately the same percentage of nitrogen in the Oxford-clay obtained in the recent Sub-Wealden exploration boring at a depth of between 500 and 600 feet, and in the subsoil at Rothamsted, taken at a depth of about 4 feet only.

It is not within the scope of the present discourse to discuss fully what is known of the actual or possible sources of the already existing combined nitrogen, the special object of the enquiry being, as intimated at the commencement, to bring to view the facts relating to the yield of nitrogen in agricultural production, which the extended period of the investigations of Mr. Lawes and myself have enabled us to establish, and to point out the relation of this to the various known or supposed sources of present periodic supplies, so as to indicate what points seem the most urgently to demand further investigation. In the papers already referred to, we have more fully considered what was known of the various actual or possible sources of the combined nitrogen which we know to exist, and to circulate, in land and water, in animal and vegetable life, and in the atmosphere, and we have pointed out how little was established of either the actual or the relative importance, in a *quantitative* sense, of the various actions by which it is admitted that free nitrogen may in nature be brought into combination. I may, however, observe that M. Boussingault and M. Schlösing have quite recently made interesting contributions to the discussion of this subject. (Compt. Rend. T. lxxvi, lxxx, lxxxi, and lxxxii.)

But whatever may be the origin of the existing combined nitrogen, or whether or not the agencies of its formation are more or less active now than during the earlier history of the earth and its atmosphere, the question arises whether, assuming the origin to be independent of the direct action of vegetation, the large accumulations within our soils and subsoils admits of any reasonable explanation? On this point it may be remarked, that ages of forest growth, or of the growth of natural herbage only grazed by animals, would doubtless leave the soil richer year by year; as the amount annually lost to it would probably

be less than even the small amount known to be annually deposited from the atmosphere, in temperate regions, at the present time ; and the accumulation would probably be greater still, were the amounts of combined nitrogen in the atmosphere, and brought down from it, greater than with us at the present time. Then, again, the influence on aqueous deposits of ages of submarine vegetation, and of the subsistence of animal life upon it, has to be considered. But a soil once broken up, and under arable culture, it is difficult to conceive of any system of agriculture by which so little nitrogen as that hitherto quantitatively determined to be annually deposited from the atmosphere would be annually exported from the land.

And now, to summarise in a few words the results of the whole discussion, I think the balance of the evidence points to the conclusion, that the answer to the question—what are the sources of the nitrogen of vegetation in general, and of agricultural production in particular, is more likely to be found in the relations of the atmosphere, and of the plant, to the soil, than in those of the atmosphere to the plant itself.

One word more in conclusion. I have, as explained at the outset, confined attention almost exclusively to one aspect of the great subject of vegetation ; but it will not be supposed that I have done so from any want of appreciation of the interest and importance of other lines of enquiry ; and allow me, before closing, to allude to a point which can hardly fail to suggest itself on an inspection of the numerous organic compounds, made by transformation in the laboratory, which are collected in the Chemical Section of this Exhibition. Without in the least degree disparaging such work, I would ask whether some of those who have become masters of such transformations, might not with advantage, armed with the experience thus gained, now devote themselves to the study of the transformations going on within the plant and the animal ? In other words, whether it would not be desirable, that some of the thought and labour now expended on transformations in the chemical laboratory should be transferred to the laboratory of nature ?

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ON

RAINFALL;

EVAPORATION AND PERCOLATION.

BY

DR. J. H. GILBERT, F.R.S., &c.

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ON

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EVAPORATION AND PERCOLATION.[1]

Dr. Gilbert remarked that Mr. Lawes and himself had been for some time engaged in percolation experiments as well as in rain-gauge determinations. He had accordingly arranged a few facts connected with those experiments extending over a period of five years. He could not give the results of so many years as Mr. Greaves, nor were theirs obtained under exactly parallel conditions. They were undertaken with a different view, their object being an agricultural one, in relation to vegetation, and the characters of soils. Mr. Greaves's percolation gauge was filled with soil artificially; they, on the other hand, took the soil just as it was; they dug down and undermined it, putting iron plates which were drilled with holes underneath; they gradually got it underpinned in that way, and built it in with brick and cement, so that they had an isolated square of soil entirely undisturbed. The area of each gauge was one-thousandth of an acre. They had one such gauge with 20 inches, one with 40 inches, and one with 60 inches depth of soil; so that they were able to answer some of the questions with regard to capillary action to which reference had been made. Of previous determinations, Dr. Dalton's had indicated that 25 per cent. of the rain percolated; those of Mr. Dickinson showed up to a certain date 42·5 per cent.; those of M. Maurice, at Geneva, 39 per cent.; those of

[1] These remarks were made, at the Institution of Civil Engineers, on the 29th of February, 1876, in the course of the discussion upon the Papers by Mr. Symons "On Floods in England and Wales in 1875," and by Mr. Greaves "On Rainfall and on Percolation."

M. Gasparin, in the South of France, 20 per cent.; those of M. Risler, near Geneva, 30 per cent.: or an average of 31·3 per cent. under different conditions in five different localities. Mr. Greaves gave 28 per cent. For a period of five years Mr. Lawes and himself found 36·8 per cent. of the rainfall percolating through 20 inches, 36 per cent. through 40 inches, and 28·6 per cent. through 60 inches. They had a natural soil, a subsoil with its natural consolidation; whereas Mr. Greaves's was an artificial soil, a much more open soil than the materials of which it was composed would form in their natural condition. (See Table I., *post*, p. 7.) The particulars of experiments on percolation by Ebermayer, in Bavaria, were given in Tables II. and III., *post*, pp. 8 and 9. To show how difficult it was to imitate soil in its natural condition, he might mention that, wishing to extend their experiments, they attempted to fill, by calculation, a number of tubes, 5 feet deep and 2 feet in diameter, with the soil of the immediately adjoining field in its exact natural condition. After putting in 3 feet of soil, pouring a great deal of water through, and applying a weight of more than 1 ton for many months, the soil had not sunk down to the 3 feet by about 6 inches. It was almost impossible by artificial means to get a soil like the natural one. Another difference in the mode of estimation was that they took the harvest year, from the 1st of September to the end of August. The rainfall in the first year was 27½ inches; in the succeeding years 29 inches, 30½ inches, 21¾ inches, and 30¾ inches, or an average of nearly 28 inches. Of those 28 inches about 10¼ inches percolated through 20 inches, 10 inches through 40 inches, and only 8 inches through 60 inches of soil; so that it was clear that capillary action had had its effect far below the depth Mr. Greaves supposed. In fact it was obvious that it had been operative below 40 inches, as was illustrated in the more detailed figures. Beginning in September, that was after warm and comparatively dry weather, there was less water going through 40 inches than through 20 inches, and less through 60 inches than through 40 inches depth of soil; and so it went on until the winter rains accumulated, when the reverse happened, and there was sometimes more through the 60 inches than through the 20 inches. (See Tables IV. and V., *post*, pp. 10 and 11.) Capillary action therefore certainly had its influence on percolation, or rather on evaporation—the complement to it—far below the depth that had been mentioned. Mr. Greaves's observations indicated an average of about 7 inches of percolation. This determination rested upon experiments made on soil covered with *vegetation*, and of course the surface of the country was mostly

so covered; but the amount of vegetation much determined the amount of percolation. (See Tables VI. and VII., *post*, p. 12.)

Ebermayer quoted Professor Woldrich as having determined the amount of percolation (2 feet deep) through turf, and through bare ground, at Salzburg and in the neighbourhood of Vienna. At Salzburg the percolation was –

In May 25·2 per cent. less through turf.
„ June 53·1 „ „
„ July 23·4 „ „
„ Aug. 29·2 „ „
„ Sept. 12·7 „ „

The difference was the least in January. In May, both at Salzburg and at Vienna, more than twice as much percolated through bare earth as through turf. From June 16–30 there percolated at Salzburg —

2·12 inches (Eng.) through bare earth.
0·02 „ „ „ turf.

The maximum difference was in June and July, and less in autumn and winter. Ebermayer concluded that in the summer half-year forest soil was the moistest; bare, open ground less moist; turf the driest.

From the results of an extended series of experiments on the amount of water given off by plants during their growth, it might be roughly estimated that, for every ton of really dry substance grown, a depth of 3 inches of rain would be evaporated through the vegetation. For every ton of hay, in its natural condition, about 2¼ inches of rain would pass through the plant. It was obvious that, where there was vegetation, percolation would be diminished, and especially where the growth extended through nearly the whole of the year, as in the case of grass land. The water would not be safe until it reached a lower depth than if the land were not covered, as in the case of the percolation experiments to which he had referred. (See also Tables VI. and VII., *post*, p. 12.) He thought that the larger amounts of percolation obtained in their own experiments than in those of Mr. Greaves were the resultant of two opposite agencies: they had no vegetation to pump the water out, but, on the other hand, Mr. Greaves's soil had no doubt been more pervious than theirs.

M. Marié-Davy, Director of the Meteorological Observatory, at Montsouris, Paris, had also made numerous experiments on the amount of water evaporated by different plants during growth,

and also on the amount evaporated from soils of different kinds, or covered with different descriptions of vegetation; but the results were too numerous and varied to be conveniently summarised in a tabular form.

With reference to some observations by Mr. Symons, he might be permitted to refer to the effects of manures in fouling water. When that gentleman visited them some time ago, he pointed out two plots of wheat, one of which had been manured in the autumn, and the other in the spring. There had been a wet winter, and under those conditions the crop manured in the spring was much better than that manured in the autumn. In dry winters it was just the contrary. At such times the crop manured in the autumn picked up more of the active manures, and less got into the drains, so that there was a better root-distribution, and eventually a better crop. Those experiments on the growth of wheat had been carried on for more than thirty years. The drain of each plot was opened, and the drainage-water occasionally collected for analysis. Dr. Voelcker and Dr. Frankland had analysed many of those waters. The results showed, on an average, that where no nitrogenous manure had been used for many years, the amount of nitrogen (as nitrates, &c.) in the drainage-water was 0·43 part per 100,000; when 41 lbs. of nitrogen per acre per annum were put on in the form of ammonia salts, the amount was 0·82 part; with 82 lbs., 1·44 part; with 123 lbs., 1·81 part; almost progressing in the ratio of the amount of nitrogen put upon the soil. Two analyses by Dr. Voelcker and four by Dr. Frankland gave 1·26 part of nitrogen per 100,000 parts of drainage-water from land manured every year with farmyard manure. (See Table VIII., *post*, p. 13.) Some of the plots were manured far more heavily than was usual in agriculture, so that there need be no fear of anything like the fouling of water referred to from ordinary agricultural operations. Of course it would be more in light soils than in heavy lands. The results described had been obtained in somewhat heavy soil. The importance of watching the matter was very great. He did not, however, think that when the matters had passed through a considerable depth of soil there was so much danger from ordinary agriculture as was sometimes supposed, although it was true the drainage-water might not indicate a very good previous history.

The following tables embodied summaries of the results to which he had referred (see pp. 7–13).

PERCOLATION AND EVAPORATION; SUMMARY OF THE RESULTS OF VARIOUS OBSERVERS.

Authority.	Conditions of the Experiments, &c.	Duration and Dates.		Percolation.	Evaporation.
		Years.		Per cent.	Per cent.
Dr. Dalton . .	("Mem. Lit. Phil. Soc. of Manchester," vol. v., part 2.) Cylinder 10 inches diameter, 3 feet deep, open at top, closed at bottom; filled with earth and sunk into the ground level with the surface; one side left exposed for access to bottles—after first year surface of soil covered with grass	3	1796–1798	25·0	75·0
Mr. Dickinson .	("Jour. Royal Agric. Soc.," vol. v.). Cylinder 12 inches diameter, 3 feet deep; perforated bottom with receptacle for collection of drainage water; grass was grown on the surface of the soil (a sandy gravelly loam) in the cylinder; evaporation included that due to vegetable growth. Average rainfall during 8 years = 26·61 inches	8	1836–1843	42·5	57·5
M. Maurice . .	Geneva ("Bibl. Universelle de Genève, Sciences et Arts," t. 1). Cylindrical iron vessel with earth, rainfall averaged over two years about 26 inches per annum	2	1796 and 1797	39·0	61·0
M. Gasparin . .	Orange, South of France ("Cours d'Agriculture," t. ii., p. 116). Experiments somewhat similar to those of M. Maurice. Average rainfall 28 inches per annum	2	1821 and 1822	20·0	80·0
M. Risler . . .	Calèves, near Nyon, Switzerland ("Archives des Sciences de la Bibliothèque Universelle," Sept. 1869). By gauging drains 1·2 mètre (about 4 feet) deep; compact and impervious subsoil; land cropped, as usual, during experiment; average rain 41 inches per annum; evaporation includes that due to vegetable growth . .	2	1867 and 1868	30·0	70·0
			Mean . . .	31·3	68·7
Mr. Greaves . .	Lee Bridge. Gauge, slate box; area 1 square yard, 1 yard deep; soil, soft earth with loam, gravel and sand mixed, trodden in, and turfed; average rainfall 25·8 inches	22	1852–1873	26·6	73·4
	Similar gauge; with sand; average rainfall 25·7 inches	14	1860–1873	83·2	16·8
	Estimated average for Home Counties; rainfall 25 inches . . .		.. ..	28·0	72·0
Lawes and Gilbert	Rothamsted, Herts. Gauge one-thousandth of an acre area; soil, rather heavy loam with clay subsoil, built in, in natural state of consolidation, with brick and cement. (Chalk below.) Average rainfall 28 inches — 20 ins. deep	5	Sept. 1870—Aug. 1875	36·8	63·2
	Do. do. do. 40 " "	5	Sept. 1870—Aug. 1875	36·0	64·0
	Do. do. do. 60 " "	5	Sept. 1870—Aug. 1875	28·6	71·4

TABLE II.—EXPERIMENTS on PERCOLATION, by EBERMAYER, in B

Gauge.—A zinc cylinder, with an area of 1 square foot, and 1, 2, or 4 deep, filled with adjacent soil and exposed to air and rain for so acquire normal physical characters.

—	Percolation through Soi Inches (English).		
	1 foot deep.[1]	2 feet deep.[1]	4 feet deep.[1]
12 Months, March 1868—*Feb.* 1869; *Mean of* 4 *Stations.*			
Open ground, bare	20·01	18·08	19·41
Forest, without litter	18·56	..	..
„ with litter	20·63	21·48	16·54
Spring. March, April, May 1868.			
Open ground, bare	5·22	5·35	5·86
Forest, without litter	4·99	..	..
„ with litter	5·69	5·75	6·00
„ with litter + or − open ground .	+0·47	+0·40	+0·14
Summer. June, July, August 1868.			
Open ground, bare	2·26	1·62	1·09
Forest, without litter	4·12	..	..
„ with litter	5·77	5·42	3·00
„ with litter + or − open ground .	+3·51	+3·80	+1·91
Autumn. Sept., Oct., Nov. 1868.			
Open ground, bare	4·41	4·08	4·09
Forest, without litter	3·96	..	..
„ with litter	3·84	4·52	3·48
„ with litter + or − open ground .	−0·57	+0·44	−0·61
Winter. Dec., Jan., Feb. 1868–9.			
Open ground, bare	8·13	7·06	8·36
Forest, without litter	5·49	..	..
„ with litter	5·34	5·78	4·07
„ with litter + or − open ground .	−2·79	−1·28	−4·29
Growing Period. April—September, inclusive, 1868.			
Open ground, bare	5·40	4·90	4·69
Forest, without litter	7·62	..	..
„ with litter	9·69	9·84	7·13
„ with litter + or − open ground .	+4·29	+4·29	+2·44

[1] French feet.

TABLE III.—EXPERIMENTS on PERCOLATION, by EBERMAYER, in BAVARIA.

Gauge.—A zinc cylinder, with an area of 1 square foot, and 1, 2, or 4 feet (Fr.) deep, filled with adjacent soil and exposed to air and rain for some time to acquire normal physical characters.

Percentage of Percolation to Rainfall.

—	Percolation through Soil. Per cent. of Rainfall.		
	1 foot deep.[1]	2 feet deep.[1]	4 feet deep.[1]
12 Months, March 1868—Feb. 1869; Mean of 4 Stations.			
Open ground, bare	54	50	53
Forest, without litter	67	..	..
" with litter	74	77	60
Spring. March, April, May 1868.			
Open ground, bare	55	56	64
Forest, without litter	70	..	..
" with litter	81	81	83
Summer. June, July, August 1868.			
Open ground, bare	19	14	11
Forest, without litter	52	..	..
" with litter	72	65	36
Autumn. Sept., Oct., Nov. 1868.			
Open ground, bare	54	51	49
Forest, without litter	60	..	..
" with litter	60	68	54
Winter. Dec., Jan., Feb. 1868–9.			
Open ground, bare	94	89	99
Forest, without litter	91	..	..
" with litter	94	97	63
Comparison of Winter and Summer Half-years.			
Open ground, bare — Oct.—March	72	67	76
Open ground, bare — April—Nov.	[illegible]	24	24
Summer less than winter	49	43	52
Forest, without litter — Oct.—March	80	..	..
Forest, without litter — April—Nov.	57	..	..
Summer less than winter	23	..	..
Forest, with litter — Oct.—March	86	77	73
Forest, with litter — April—Nov.	75	76	62
Summer less than winter	11	11	11
July only.			
Open ground, bare	11	6	7
Forest, with litter	58	61	34

[1] French feet.

TABLE IV.—RAIN and PERCOLATION at ROTHAMSTED, HERTS.
September 1, 1870, *to August* 31, 1875.

—	Rainfall.	Percolation through Soil.			Difference reckoned as Evaporation.		
		20 inches deep.	40 inches deep.	60 inches deep.	20 inches deep.	40 inches deep.	60 inches deep.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Sept. 1870—Aug. 1871	27·55	9·64	9·42	5·81	17·91	18·13	21·74
„ 1871 „ 1872	29·02	9·69	9·40	8·24	19·33	19·62	20·78
„ 1872 „ 1873	30·66	14·35	13·67	12·03	16·31	16·99	18·63
„ 1873 „ 1874	21·69	5·47	5·11	3·61	16·22	16·58	18·08
„ 1874 „ 1875	30·74	12·25	12·72	10·30	18·49	18·02	20·44
Average per annum .	27·93	10·28	10·06	8·00	17·65	17·87	19·93
September	2·88	0·68	0·43	0·30	2·20	2·45	2·58
October	3·19	1·37	1·09	0·76	1·82	2·10	2·43
November	2·08	1·41	1·30	1·01	0·67	0·78	1·07
December	2·15	1·52	1·51	1·14	0·63	0·64	1·01
January	3·11	2·15	2·43	2·08	0·96	0·68	1·03
February	1·47	0·69	0·75	0·59	0·78	0·72	0·88
March	1·43	0·53	0·57	0·47	0·90	0·86	0·96
April	1·76	0·26	0·28	0·22	1·50	1·48	1·54
May	1·91	0·21	0·23	0·19	1·70	1·68	1·72
June	2·77	0·48	0·43	0·36	2·29	2·34	2·41
July	3·47	0·97	1·03	0·87	2·50	2·44	2·60
August	1·71	0·01	0·01	0·01	1·70	1·70	1·70
Total	27·93	10·28	10·06	8·00	17·65	17·87	19·93
Average per month .	2·33	0·86	0·84	0·67	1·47	1·49	1·66

TABLE V.—RAIN and PERCOLATION at ROTHAMSTED, HERTS.
September 1, 1870, *to August* 31, 1875.

—	Rainfall.	Percentage of Percolation to Rainfall.					
		Percolation through Soil.			Difference reckoned as Evaporation.		
		20 inches deep.	40 inches deep.	60 inches deep.	20 inches deep.	40 inches deep.	60 inches deep.
	Inches.						
70—Aug. 1871	27·55	34·9	34·2	21·1	65·1	65·8	78·9
71 ,, 1872	29·02	33·4	32·4	28·4	66·6	67·6	71·6
72 ,, 1873	30·66	46·8	44·6	39·2	53·2	55·4	60·8
73 ,, 1874	21·69	25·2	23·5	16·6	74·8	76·5	83·4
74 ,, 1875	30·74	39·9	41·4	33·5	60·1	58·6	66·5
Average . .	27·93	36·8	36·0	28·6	63·2	64·0	71·4
ber	2·88	23·6	14·9	10·4	76·4	85·1	[illegible]
. . . . . .	3·19	42·9	34·2	[illegible]	57·1	65·8	76·2
er	2·08	67·8	62·5	48·6	32·2	[illegible]	51·4
r	2·15	70·7	70·2	53·0	29·3	29·8	47·0
. . . . . .	3·11	69·1	78·1	66·9	[illegible]	21·9	33·1
y	1·47	47·0	51·0	[illegible]	53·0	49·0	[illegible]
. . . . . .	1·43	37·0	39·9	32·9	63·0	[illegible]	67·1
. . . . . .	1·76	14·8	16·0	12·5	85·2	[illegible]	87·5
. . . . . .	1·91	11·0	12·0	9·9	[illegible]	88·0	90·1
. . . . . .	2·77	17·3	15·5	13·0	82·7	84·5	87·0
. . . . . .	3·47	28·0	29·7	25·1	72·0	70·3	74·9
. . . . . .	1·71	0·6	0·6	0·6	99·4	99·4	[illegible]
l.	27·93						
age	[illegible]†	36·8	36·0	28·6	63·2	64·0	71·4

TABLE VI.—EXPERIMENTS at ROTHAMSTED, HERTS, ILLUSTRATING the INFLUENCE O VEGETATION on EVAPORATION. RESULTS RELATING to PERMANENT GRASS LAND.

—	Plot 3. Without Manure.	Plot 9. Mineral Manure and Ammonia-salts.	Plot 14. Mineral Manure an Nitrate of Soda.
	Cwt.	Cwt.	Cwt.
Produce of Hay per acre.			
Average 15 (or 13 years, 1856–1870 . . .	22¾	52¼	57⅞
Year of drought, 1870	5¾	29½	56¼
Deficiency in 1870	17	22¾	1⅝
Manured more than unmanured in 1870 . .	..	23¾	50½
Moisture in the Soils (dried at 100° C.) at different depths.			
	Per cent.	Per cent.	Per cent.
Samples collected, July 25–6, 1870. First 9 inches	10·83	13·00	12·16
Second " "	13·34	10·18	11·80
Third " "	19·23	16·46	15·65
Fourth " "	22·71	18·96	16·30
Fifth " "	24·28	20·54	17·18
Sixth " "	25·07	21·34	18·06
Mean	19·24	16·75	15 19
Estimated quantities of Water per acre.[1]			
	Tons.	Tons.	Tons.
Total to the depth of 54 inches	1,546	1,346	1,221
Manured less than unmanured land . . .	..	200	325

TABLE VII.—DITTO DITTO. RESULTS RELATING to the GROWTH of BARLEY.

—	Barley Land.	Adjoining Fallow Land.[2]	Fallow La more than Barley Lan
	Per cent.	Per cent.	Per cent.
Moisture in the Soils (dried at 100° C.) at different depths.			
Samples collected June 27–8, 1870. First 9 inches	11·91	20·36	8·45
Second " "	19·32	29·53	10·21
Third " "	22·83	34·84	12·01
Fourth " "	25·09	34·32	9·23
Fifth " "	26·98	31·31	4·33
Sixth " "	26·38	33·55	7·17
Mean	22·09	30 65	8·56
Estimated quantities of Water per acre.[1]			
	Tons.	Tons.	Tons.
To the depth of 54 inches	1,863	2,772	909

[1] The estimates given above of the "quantities of Water per acre" must of course be take approximate and illustrative only.
[2] About 0·65 inch of rain had fallen ten days previous to the collection of the soils, and 0·16 three days before; and for several days since the heavier rainfall some soil had been thrown u uncropped land, probably retarding evaporation. Hence doubtless part of the excess in the uncro land.

TABLE VIII.—COMPOSITION of DRAINAGE WATER from PLOTS DIFFERENTLY MANURED; BROADBALK FIELD, ROTHAMSTED. WHEAT EVERY YEAR, COMMENCING 1844. NITROGEN as NITRATES and NITRITES, per 100,000 parts of WATER.

Dr. Voelcker's and Professor Frankland's Results.

Samples collected at different periods of the year in 1866, 1867, 1868, 1872, *and* 1873.

Plots.	—	Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage Water.					
		Dr. Voelcker's Results.		Dr. Frankland's Results.		Mean.	
		Experiments.		Experiments.		Experiments.	
2	14 tons farmyard manure, every year	2	1·606	4	0·922	6	1·264
3-4	Without manure, every year .	5	0·390	6	0·316	11	0·353
5	Mineral manure alone . . .	5	0·506	6	0·349	11	0·428
6	" " and ammonia-salts (41 lbs. nitrogen) . .	5	0·853	6	0·793	11	0·823
7	Mineral manure and ammonia-salts (82 lbs. nitrogen) . .	5	1·400	6	1·477	11	1·439
8	Mineral manure and ammonia-salts (123 lbs. nitrogen) .	5	1·679	6	1·951	11	1·815
9	Mineral manure and nitrate soda (82 lbs. nitrogen) . .	5	1·835	5	1·039	10	1·437

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TABLE VIII.—COMPOSITION of DRAINAGE WATER from PLOTS DIFFERENTLY MANURED; BROADBALK FIELD, ROTHAMSTED. WHEAT EVERY YEAR, COMMENCING 1844. NITROGEN as NITRATES and NITRITES, per 100,000 parts of WATER.

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Plots.	—	Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage Water.					
		Dr. Voelcker's Results.		Dr. Frankland's Results.		Mean.	
		Experiments.		Experiments.		Experiments.	
2	14 tons farmyard manure, every year	2	1·606	4	0·922	6	1·264
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8	Mineral manure and ammonia-salts (123 lbs. nitrogen) .	5	1·679	6	1·951	11	1·815
9	Mineral manure and nitrate soda (82 lbs. nitrogen) . .	5	1·835	5	1·039	10	1·437

FREEDOM IN THE GROWTH AND SALE

OF THE

CROPS OF THE FARM,

CONSIDERED IN RELATION TO THE INTERESTS OF

THE LANDOWNER & THE TENANT FARMER.

By J. B. LAWES, LL.D., F.R.S., &c.

A Paper read before the Society of Arts, December 12th, 1877.

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FREEDOM

IN

THE GROWTH AND SALE OF CROPS.

THE agriculture of Great Britain, considered as a commercial undertaking, may be said to be carried on by two partners; the one providing the capital in land and buildings, and the other the capital in live stock, implements, manures, and that required for the payment of wages, &c. The interest of the one partner is permanent; he may be called the owner of the business; whilst that of the other is limited to a period mutually agreed upon. The landowner receives interest upon his capital in the form of a fixed annual payment, or rent. The profits of the tenant, on the other hand, are fluctuating, for they depend, not only on the fixed amount of rent paid, but upon whether the seasons are favourable or unfavourable, upon his skill in management, and upon a variety of other circumstances. The tenant gets a higher rate of interest on his capital than the landowner, as is to be expected that he should do, since he takes a more active share in the management of the business. The landowner, however, controls some of the most important operations on the farm. He decides what crops may, and what crops may not, be grown; what produce may be sold, and what may not be carried off the farm. The tenant attends to the cultivation of the land, buys and sells stock, and, subject to the important restrictions above-mentioned, manages the farm in the manner which he considers the most conducive to his own interests.

It is frequently assumed that the interests of the landowner and of the tenant are somewhat conflicting; and probably much of the reluctance of the tenant to furnish statistics arises from a fear that the knowledge thus provided would induce the landowner to demand a larger share in the profits of the business. It appears to me, however, that the interests of the landowner and the tenant are, in every respect but one, identical. The tenant acts like any other man of business. After providing for the maintenance and education of his family, he saves as much as he can to place them out in life. A farmer's son generally becomes a farmer. If the capital of the farmer be reduced, a reduction of rent is sure to follow, sooner or later. With large profits, on the other hand, there is an increase in the amount of capital to be invested in farming, there is more competition for farms, and rents rise. Excepting in the form of loans by bankers to farmers, probably not much capital goes into the business of farming from external sources. A certain amount is brought into it by those who, having been successful in other pursuits, take up with farming; but whether they are generally successful in making a profit out of it is very doubtful. Their farming must rather be classed with that of the landowner, who derives little other benefit from it than the pleasure which the occupation affords.

I have said that the interests of the landowner and the tenant farmer are identical in every respect but one. Those of the landowner are permanent, whilst those of the tenant are limited. Accordingly, with a view of maintaining the fertility of his soil, the landowner introduces into his agreements certain restrictive covenants, in regard to cropping, and to the sale of the produce of the farm. He argues that any profit which might accrue to the tenant from the removal of such restrictions would be obtained at his expense, and would reduce the letting capability of his land. It must be conceded that, as such restrictions have been in force for so long a time, the burden of proof that

they might be removed without injury to the landowner rests upon the tenant, or upon those who advocate his claims.

This brings me to the special subject of my address to you this evening, namely—*Freedom in the growth and sale of the crops of the farm, considered in relation to the interests of the landowner and the tenant farmer.*

The restrictions introduced into the covenants by the landowner for his protection may be briefly summed up as follows:—

Not to grow two white straw crops in succession.

Not to sell straw, hay, roots, or, in fact, any fodder crops, off the farm.

In some districts a second white straw crop in succession may be taken in the course of a rotation; that is to say, three in five years, instead of two in four years. In such cases, it is generally stipulated that the second corn crop shall differ from the first; that wheat shall not follow wheat, nor barley barley.

In regard to these restrictions, I propose to consider the following questions:—

Are they necessary for the protection of the landowner?

If once necessary, are they equally so now?

Do not a comparison between past and present prices of agricultural produce, our increased knowledge in regard to the action of manures, and to the exhaustion of soils, and the fact that large external sources of supply of fertilising materials are now at our command, justify us in concluding that these restrictions might safely be modified, or even in some cases removed?

The arguments for and against the modification or removal of restrictive covenants, may be briefly stated thus:—

On Behalf of the Landowner.

That long experience has shown such restrictions to be necessary to prevent undue exhaustion of the soil.

That to give power to the tenant to grow what crops he

pleases, and to sell straw, hay, roots, and fodder crops generally, would exhaust the land, be prejudicial to the interests of a succeeding tenant, and would render the letting of the farm more difficult, if not actually reduce its letting value.

That even if the tenant were permitted to grow and sell what crops he pleased, it would not be to his interest to do otherwise than he is now allowed to do.

That, all things considered, restrictive covenants are beneficial to both the landowner and the tenant.

On Behalf of the Tenant.

The restrictions on the sale of straw, hay, &c., artificially enhance the prices of those commodities, are therefore injurious to the consuming public, and amount to protection in favour of the few farmers who are permitted to sell them.

That, in the event of the outgoing tenant having the power to sell all the products off the farm, the incoming tenant could still purchase all he required; since, having no carriage for removal to pay for, he would have the advantage over all other purchasers.

That restrictive covenants prevent the tenant from applying his skill and capital to the best advantage.

That, at least in a large majority of cases, the modification or removal of existing restrictions would not prove injurious to the more permanent interests of the landowner.

In these few paragraphs, I have endeavoured to summarise the arguments which would probably be used against, or for, any change in the usual restrictive covenants. I have, however, omitted from those which the tenant might adduce in favour of change, some which, whilst they would materially strengthen his case, I should perhaps hardly be justified in making him responsible for. If we compare the agriculture of the present day with that of half or three-quarters of a century ago, we shall notice some changes which are evident to all. The actual

and relative prices of meat, grain, straw, and hay, are very different now from what they were then. The farmer has now at his command enormously increased and increasing supplies of purchasable cattle foods and manures. There are other changes which are not so obvious at first sight, but which are equally important, such as our greatly increased knowledge of the action of manuring substances, and of the capabilities and of the exhaustion of soils.

The agriculture of the last century consisted of little else than taking several corn crops in succession, until the produce did not pay the cost of cultivation, and then allowing the land to recover its fertility by rest. During this period, it afforded scanty food for stock. After a time it was again broken up; and so on. As population and the demand for food increased, the periods of rest were shortened, and the land was rarely left more than two or three years in succession without being ploughed up and a corn crop sown. Still later, a rotation of crops, which required the land to be broken up every year, was adopted.

Under this more modern system, the demands upon the soil would obviously be greater; and, accordingly, it was considered expedient to place some restriction upon the course of cropping, and the sales by the tenant, to prevent him from sending off the farm too much of the produce of the soil. By degrees such covenants became almost universal; and at the present time very few tenants are allowed perfect freedom of action.

Looking at the various things which a farmer may and may not do, it is difficult, if not impossible, to give any rational explanation of their adoption. Some things which he is permitted to do, and which are considered consistent with good husbandry, may be as exhausting to the soil as the growth of a second corn crop, or the sale of straw. Thus, deep cultivation, liming, draining, and bare fallow, have all for their object to enable the farmer to take more out of the soil without putting

anything into it. On the other hand, very few farmers find it to their interest to exhaust the land as much as they are permitted to do under the provisions of their leases or agreements. Whether they purchase cattle food, or manures, or not, they generally consume on the farm a portion of the corn which they might, if they please, carry to market. It is, indeed, only soils of high natural fertility that can furnish sufficient produce to pay rent, and the expenses of cultivation, and also yield a profit to the tenant, without some aid from external sources.

It is now more than forty years since I commenced experiments at Rothamsted, with different manuring substances, first with plants in pots, and afterwards in the field; and I have the record of more than eighty different chemical substances, or combinations, having been tried in one year in the very early days of those experiments. In the course of their extended and continued prosecution up to the present time, it has been found that some of the most important crops of the farm can be grown for twenty, or even more than thirty, years in succession on the same land, in full agricultural quantity, by means of chemical salts alone, of which the three most important constituents are nitrogen, phosphoric acid, and potass. As, during the whole of the long periods mentioned, manures supplying these substances have been used, in some cases separately, and in others in various combinations, year after year, on the same plot of land, and with the same crop, it is obvious that the results obtained have furnished the basis for forming a pretty accurate judgment of what constitutes exhaustion of the soil. They also enable us to determine which of the constituents of the crops are derived from the atmosphere, and which must be supplied by, and are taken from, the soil.

Time will not permit me to direct your attention to the results of these experiments except in the briefest possible manner. At the outset I must observe that the experiments to which I am about to refer are conducted without reference to

the question of economy or profit; and I must beg you, therefore, to dismiss from your minds any consideration as to their cost. What I wish to illustrate, and to impress upon your minds, is, that the three constituents of manures—nitrogen, phosphoric acid, and potass—are not only the most effective on the growth of crops, and, therefore, the most important, but they are also those which, in proportion to the requirement for them, are generally contained in the soil in only small available amount compared with the other constituents of crops thence derived. The economical application of these essential elements of plant food is a subject which would require entirely separate consideration. It would involve an inquiry into the relative economy of manure made by stock and that purchased from external sources; into the natural fertility of soils, or their capability to yield up annually more or less of plant food; and into the prices at which straw, hay, roots, &c., could be more profitably consumed on, or sold off, the farm.

Permanent Grass.—The application of artificial manures alone, containing nitrogen, phosphoric acid, and potass (with some other constituents of known little effect), for twenty-two years in succession, has given an average annual crop of hay of nearly three tons per acre. Twice during the period a second crop has been cut without further manuring; and it has, on each occasion, yielded nearly 2½ tons more.

Permanent Wheat.—In like manner, artificial manures used alone, supplying nitrogen, phosphoric acid, and potass, have given an average, over twenty-five years, of 36¾ bushels of dressed corn, and more than 2 tons of straw, per acre per annum. The produce of the present year was 40 bushels of dressed corn, and 1 ton 14 cwts. of straw. No dung has been applied to this land for 38 years.

Permanent Barley.—In a similar way, artificial manures alone, containing nitrogen and phosphoric acid, *without potass*, have given an average, over 2 years, of 6 quarters of barley,

and nearly 1½ ton of straw, per acre per annum. Anoth plot, with the same amounts of nitrogen and phosphoric aci but with potass added, has given on the average, only a fracti of a bushel more corn, and less than 2 cwts. more straw, p acre per annum. No dung has been applied to this land for years. It is evident, therefore, that, up to the present tim the soil itself has yielded up as much potass as was requir for the large annual crop above-mentioned.

Permanent Root Crops.—Root crops are generally consider to be more dependent on applied manure than any other; a this opinion is fully confirmed by the Rothamsted experimen In a continuously unmanured four-course rotation, which h now extended over a period of 30 years, the root crop of t first course, though small, was very much heavier than it h been since, having been quite insignificant, and averaging le than a ton per acre per annum, over the last six courses. No withstanding this, the barley averaged 36¼ bushels, and t wheat 30 bushels, over the seven unmanured courses.

With the exception of three years, during which barley w grown without manure, roots have been grown over an area 8 acres, without manure, with farmyard manure, and wi different artificial manures, from 1843 up to the present tin as under:—

Norfolk whites	6	years.
Swedes	4	,,
(Barley)	(3)	,,
Swedes	15	,,
Sugar-beet	5	,,
Mangels	2	,,
Roots, total	32	years.

In the case of the Norfolk whites and Swedes, the leaves well as the roots were removed from the land; but in the ca of the sugar-beet and mangels, the leaves were spread upon t

land, and the roots only were removed. In 1876, the produce of roots (mangels) with artificial manure alone, containing nitrogen, phosphoric acid, and potass, was 22 tons 11 cwts., and in the present year, 1877, it has been 22 tons 2 cwts. No dung has been applied to these plots for nearly 40 years.

Some specimens of the produce of the present season, grown with artificial manure alone, on land which has not received any dung for so many years, are to be seen on the table. Compared with the monsters usually exhibited, these are of very moderate dimensions. They are grown very close together, 26 inches between the rows, but only 11 inches from plant to plant in the rows. Such roots will, however, contain a much higher proportion of dry or solid matter than larger ones; and samples from the same plots as those on the table have this year given to analysis from 9 to 10 per cent. of sugar, or more than the amount of total dry or solid substance in many monster roots.

From these few illustrations, it must be evident that manures supplying nitrogen, phosphoric acid, and potass, will keep up the fertility of my soil, and enable it to produce crops of hay, corn, and roots, in full agricultural quantity, for very many years in succession. Nor is this result dependent on anything exceptional in the quality of this particular soil; on the contrary, I do not hesitate to give it as my opinion, that cultivated soils generally, whether in Great Britain or elsewhere, which have become impoverished by cropping, would, in a greater or less degree, be restored to fertility, by the application of manure supplying, in an available condition, one or more of the three constituents, nitrogen, phosphoric acid, and potass.

It may be said roughly that from 90 to 95 per cent. of the dry substance of the crops I have referred to, as grown by artificial manures alone, consisted of organic matter of which the manures applied contained none. There can be no doubt that the constituents of this organic matter were derived, directly or indirectly, from the atmosphere, and not from either

the soil itself or the manures. And, if a system of compensation to outgoing tenants for unexhausted manures should at any time be generally adopted and enforced, there can be little doubt that the three constituents of crops, soils, and manures, to which I have especially directed your attention, will alone be admitted as subjects of claim; and the difficulty of estimating the amount of them remaining in the soil in a condition capable of being yielded up to growing crops within a definite period of time, will tax to the utmost the knowledge and skill of the valuer or arbitrator.

Assuming, then, that nitrogen, phosphoric acid, and potass are the most important constituents of manures, and are those in which our soils are the most likely to become deficient by indiscriminate cropping, let us see how the stores of them within the soil are affected under the adoption of an ordinary four-course rotation, subject to the restrictive covenants usually enforced.

It was due to the sagacity of the father of the present Earl of Leicester, that this system of rotation was brought into general use on the light lands of Norfolk. At the commencement of the present century, large areas of those soils, which are now extremely productive, were considered to be not worth cultivation. In themselves they were very poor in the elements of fertility, and very little could be purchased from external sources. Consequently, it was of the utmost importance that the sales by the tenant should be so regulated that a minimum amount of the most essential fertilising constituents should be given in exchange for a given amount of money. In other words, that for the same amount of money received by the tenant for his produce, he should export from the soil as little as possible of the constituents essential for the growth of future crops.

In the following table is shown the amounts of nitrogen, phosphoric acid, and potass, that would be lost to the farmer in

the disposal of different kinds of produce, in equal money value, reckoned according to the prices prevailing sixty or seventy years ago; and, for convenience of illustration, £10 worth of produce is assumed to be sold in each case. In the upper division of the table are enumerated those products which, according to the usual restrictive covenants, may, and in the lower division those which may not, be sold off the farm.

Constituents contained in £10 worth of each Description of Produce, reckoned at the Prices of Sixty or Seventy Years ago.

PRODUCE THE SALE OF WHICH IS ALLOWED.

PRODUCE.	Nitrogen.	Phosphoric acid.	Potass.	Total.
	lbs.	lbs.	lbs.	lbs.
Live weight of animal	18·0	10·0	1·3	29·3
Wheat grain	27·0	13·0	8·0	48·0
Barley grain	24·0	12·0	8·0	44·0
Oat grain	30·0	9·5	7·0	46·5
Average	24·8	11·1	6·1	42·0

PRODUCE THE SALE OF WHICH IS PROHIBITED.

PRODUCE.	Nitrogen.	Phosphoric acid.	Potass.	Total.
	lbs.	lbs.	lbs.	lbs.
Clover hay	120·0	32·0	103·0	255·0
Meadow hay	80·0	23·0	90·0	193·0
Wheat straw	58·0	32·0	85·0	175·0
Barley straw	65·0	27·0	110·0	202·0
Oat straw	70·0	25·0	120·0	215·0
Average	78·6	27·8	102·0	208·0

It will be seen how admirably a system of rotation, with covenants permitting the sale of meat and grain, but prohibiting the disposal of hay or straw, was calculated to conserve the three important constituents of soils and manures—nitrogen,

[redacted]

phosphoric acid, and potass. Thus, of nitrogen, by the sale ol £10 worth of meat, the tenant would only send off the farm 18 lbs., whereas in £10 worth of clover hay he would expor 120 lbs., and in £10 worth of meadow hay, 80 lbs. O phosphoric acid, in £10 worth of meat, he would send off onl 10 lbs.; but in £10 worth of clover hay, 32 lbs., and in £1(worth of meadow hay, 23 lbs. Of potass, in £10 worth of meat he would send off only 1½ lbs., and in £10 worth of clover hay 103 lbs, and in £10 worth of meadow hay, 90 lbs. Again, o nitrogen he would only send off from 24 to 30lbs. in £10 wortl of wheat, barley, or oat grain; whereas in £10 worth of wheat barley, or oat straw, he would export from two or three time as much. In £10 worth of wheat, barley, or oat grain, h would sell from 9½ to 13 lbs. of phosphoric acid; but in wheat barley, or oat straw to the same value, he would sell abou twice and a half as much. Lastly, of potass, there would be n £10 worth of wheat, barley, or oat grain, only 7 or 8 lbs.; bu in £10 worth of wheat, barley, or oat straw, considerably mor than ten times as much.

Leaving out of view the details, and confining attention onl to the lines of mean results in the table, it will be seen that, b the disposal of £10 worth of the produce the sale of which i prohibited, there would, on the average, be more than thre times as much nitrogen, about two and a half times as muc phosphoric acid, and more than sixteen times as much potas lost to the farm, as in £10 worth of the produce the sale c which is allowed.

Thus, modern science not only confirms the value of a syster introduced about three quarters of a century ago, but it show clearly upon what its value really depended.

In the next table is shown the amounts of nitrogen, phos phoric acid, and potass, in £10 worth of each of the sam descriptions of produce, reckoned according to their fair averag selling price in recent years.

Constituents contained in £10 worth of each Description of Produce, reckoned at the Average Prices of Recent Years.

PRODUCE THE SALE OF WHICH IS ALLOWED.

PRODUCE.	Nitrogen.	Phosphoric acid.	Potass.	Total.
	lbs.	lbs.	lbs.	lbs.
Live-weight	9·0	5·0	0·65	14·7
Wheat grain	36·0	17·3	10·7	64·0
Barley grain	32·0	16·0	10·7	58·7
Oat grain	40 0	12·7	9·3	62·0
Average	29·3	12·8	7·8	50·0

PRODUCE THE SALE OF WHICH IS PROHIBITED.*

PRODUCE.	Nitrogen.	Phosphoric acid.	Potass.	Total.
	lbs.	lbs.	lbs.	lbs.
Clover hay	72·0	19·2	61·8	153
Meadow hay	64·0	18·4	72·0	154
Wheat straw	32·4	17·9	47·4	97
Barley straw	36·3	15·1	61·4	113
Oat straw	39·1	14·0	67·0	120
Average	48·8	16·9	61·8	127

It will be observed that, at the present day, the farmer gives much less of the three constituents in live weight of animal, hay, or straw, for £10, than he did three-quarters of a century ago; or, in other words, the prices of these articles are much higher now than they were then. On the other hand, wheat, barley, and oat grain, are cheaper now than they were then, and he has to give more of them, and of their important constituents, for the same money, than he did formerly.

* In the table, roots are not included in the list of produce the sale of which is prohibited, as they have no sufficiently-established price in the market. They, moreover, vary very much in composition, according to the description, the soil, the season, and the manuring. But supposing mangolds or swedes were sold off the farm at £1 per ton, £10 worth of them would export from 40 to 50 lbs. of nitrogen, or much more than £10 worth of straw; 12 to 16 lbs. of phosphoric acid, or about as much as £10 worth of straw; and from 60 to 80 lbs. of potass, or again as much as, or more than, £10 worth of straw. Again, reckoning potatoes at £5 per ton, £10 worth of them would export about 16 lbs. of nitrogen, about 7 lbs. of phosphoric acid, and about 24 lbs of potass; or less than half as much of each of them as £10 worth of straw.

The fact is, that, by the sale of £10 worth of straw, the exhaustion of nitrogen would, at the present time, be only about the same as by the sale of £10 worth of grain, whereas formerly it was from two to three times as great. Of phosphoric acid, again, the loss to the land, by the sale of £10 worth of straw, is now only about the same as by the sale of £10 worth of grain, whereas formerly it was more than twice as great. Lastly, of potass, whilst formerly considerably more than ten times as much would be sold off in £10 worth of straw than of grain, at the present time only between five and six times as much would be exported in £10 worth of straw as in £10 worth of grain.

Again, calling attention to the mean results only, it is seen that, in consequence of the change in prices which has taken place between the two periods, the amount of nitrogen now sold off in £10 worth of meat or grain would be 29 lbs., whilst that in the same value of the produce the sale of which is prohibited would be 49 lbs., or little more than one and a-half time as much; whilst formerly it was more than three times as much. Of phosphoric acid the average amount in £10 worth of the saleable products would, at the present time, be under 13 lbs., and in that of the prohibited products about 17 lbs., or less than one and a-half times as much in the latter; whilst, at the former period, it was two and a-half times as much. Of potass, £10 worth of the saleable products would now contain, on the average, under 8 lbs., whilst the prohibited products would contain 62 lbs., or about eight times as much; whilst formerly £10 worth of the prohibited products contained more than 16 times as much potass as the same value of the saleable product.

The obvious result of all this is, that, at the present prices of the different descriptions of produce, the tenant would exhaust the land of nitrogen, phosphoric acid, and potass, very much less by the sale of £10 worth of meat than he would three quarters

of a century ago; more by the sale of a given money's worth of grain, but much less by the sale of a given money's worth of hay or straw, now than formerly; so that, to compensate for such sale of hay or straw, it would be necessary to import less of these constituents from external sources at the present time than at the former period.

To illustrate the matter in a practical way, let us assume that the farmer of 1807, and the farmer of 1877, were each permitted to sell those products the sale of which is at present prohibited, on condition that he purchased and brought on to the land the amount of nitrogen, phosphoric acid, and potass, which he carried off in the produce sold. Of course this would have been impossible in the case of the farmer of 1807, as the necessary artificial manures were not then in the market. But, assuming that the same sources were available to him, and at the same prices as at present, how would the case stand? After selling £10 worth of the produce the sale of which is now prohibited, the farmer of 1807 would have to expend about 111 shillings to restore the constituents exported, leaving him only 89 shillings out of the £10 received. The farmer of 1877, exporting much less in £10 worth of these products, would have to expend only about 69 shillings to return the nitrogen, phosphoric acid, and potass, retaining in his pocket 131 shillings of the £10 he had received, or about 1½ time as much.

At the time when the four-course rotation and the restrictive covenants connected with its adoption were introduced, nothing was, however, known of the importance of nitrogen, phosphoric acid, and potass. Between the years 1805 and 1812, Sir Humphrey Davy delivered a course of lectures on agricultural chemistry, in which was embodied all the best knowledge of the day relating to the subject. He does, indeed, mention nitrogen, phosphoric acid, and potass, in various parts of his lectures; and even quotes experiments on vegetation, which he made

with saline substances containing them; but still he seems to attribute comparatively little importance to them as constituents of soils or manures. Referring to the mud of the Nile as an example of one of the best natural soils, he gives an analysis of it by a French chemist, in which neither of these important constituents is mentioned. Speaking of fallow, he says:— "The vague ancient opinion of tho use of nitre and of nitrous salts in vegetation, seems to have been one of the principal speculative reasons for the defence of summer fallows." Sir Humphrey Davy's lectures appear to have excited very little attention among agriculturalists, and to have exerted little or no influence on agriculture. In fact, from the date of his lectures up to the appearance of Liebig's first work on the subject in 1840, a period of about 30 years, the application of chemistry to agriculture was little thought of in this country. It is somewhat remarkable that, during the time when Sir Humphrey Davy was delivering his lectures, he and other eminent scientific men of the day were accustomed to visit in the adjoining parish to that in which I reside, at the house of Sir John Sebright, the grandfather of the present baronet. Sir John attained considerable eminence as an agriculturalist, especially as a breeder of stock; and he informed me that the subject of the application of chemistry to agriculture was frequently discussed at those gatherings, and the general opinion was that little or no benefit would result from it.

Exhaustion of the Soil.

Some years ago, I read a paper before the London Farmers' Club,* in which I endeavoured to define what is known in agricultural language as "condition" of soil, and to draw a distinction between it and what may be called the "natural fertility" of the land. "Condition" I described as representing those fertilising matters within the soil which had been accumulated

* "Exhaustion of the Soil in relation to Landlords' Covenants, and the Valuation of Unexhausted Improvements." (Read April 4, 1870.)

in it by the operations of the tenant. It was to the value of these, that the framers of the Agricultural Holdings Act sought to give the outgoing tenant a legal claim. The almost complete evasion of that Act appears to be due to a fear that the great ignorance which exists as to the effects of unexhausted manures, might lead to large and unjust claims being put forward or awarded, rather than to any desire to deprive the tenant of that which is justly his. That such a fear is not altogether devoid of foundation, my own experience when called as a witness in connection with a claim for compensation in Ireland sufficiently proves. If, however, a tenant had freedom of action as to cropping and the disposal of his produce, he would have little cause to trouble himself about compensation for unexhausted manures.

From the point of view of practical agriculture, exhaustion of the soil may be defined as such a condition brought about by the removal of crops, that a good or profitable crop of the same description of produce as the one last taken, cannot be grown without fresh manuring. For example, in most descriptions and conditions of soils, a growing corn crop will so far exhaust the nitrogen available for such crops within its reach, that a second corn crop would find a deficiency of it unless it were supplied by manure. In fact, in almost all cases, a supply of available nitrogen by manure would largely increase the growth of a second corn crop. Assuming that a second corn crop were so taken, and the straw as well as the corn sold off the farm, there would obviously be a large export of phosphoric acid and potass; but to what extent the soil would, in an agricultural sense, be "exhausted" thereby, would entirely depend upon the "natural fertility," and the "condition" of the particular soil. The question of—in what degree, or in what way, restoration should be made, is one for the exercise of the judgment and intelligence of the tenant, founded on his knowledge and experience of the quality and condition of his soil.

After very careful consideration of the subject, I am disposed to conclude that no stipulation, on the part of the landowner, to the effect that a given quantity of manure, natural or artificial, shall be brought upon the farm from external sources for a given quantity of produce exported, would be generally applicable, or obviate the difficulty supposed. There would be no difficulty in estimating the amounts of nitrogen, phosphoric acid, and potass, sent off the farm in known descriptions and amounts of produce; nor would there be any in determining in what descriptions and amounts of manure the constituents exported in the produce could be replaced. But, to use a common expression, such an arrangement "would not work." Indeed, the clause often introduced into agreements, binding the tenant to bring back rotten dung, or an "equivalent" in artificial manure, might be so taken advantage of as to reduce rather than to restore the fertility of the soil.

In reference to the subject of the restoration of the constituents removed, I may quote an extreme case by way of illustration. On one of the experimental plots at Rothamsted, the potass of both the straw and the corn of 25 large crops of barley has been removed from the land without any restoration of potass during the whole of the period. On another plot, in the same field, potass has been applied, in addition to the same manures, every year, for 25 years in succession, without increasing the crop more than by a fraction of a bushel of corn, and about 1½ cwt. of straw, per acre per annum. It surely would be unreasonable to call upon the tenant to be at the expense of replacing the potass of the exported produce in purchased manures, if the soil itself were competent to supply the amount required. It is true that we are, at present, very ignorant in regard to the resources of various descriptions of soil; and it is quite certain that very many soils could not yield the amount of potass that has been taken from my soil, in the case I have just cited. But assuming a soil to be deficient in available

potass for the crops that the tenant wished to grow, would not he, rather than the landowner, be the sufferer if he attempted to grow them without supplying it? If he were at the expense of supplying sufficient available nitrogen and phosphoric acid to produce the crops he desired, assuming the soil to contain an abundance of potass, and if, instead, the soil were deficient in potass, the manures he did apply would not have their full effect, and he would incur a corresponding loss of money in the operation.

If the motto "Practice with Science" have any real significance as applied to agriculture, the union of the two should at least teach the lessons that the resources of the soil itself are to be turned to profitable account; that those constituents which the soil itself will yield in abundance need not be added; but that those in which it is deficient should be applied to it in the cheapest possible way. Experience alone can teach the farmer what are the resources of the soil with which he has to deal. Light land farmers know full well that the inherent resources of their soils have a limit which is very soon reached; that a too liberal use of nitrogen, in the form of nitrate of soda, is liable to be followed by mildew, or a laid crop; and they are thus warned that they cannot, without loss to themselves, disturb the healthy balance of plant food.

The soil of many of the experimental plots at Rothamsted has been subject to a degree of exhaustion such as cannot possibly take place under any conceivable system of commercial agriculture. But the growth of corn, hay, or root crops, year after year, on the same land, for a quarter of a century or more, without manure, with individual manures, and with various combinations, has provided important data for judging of the available resources of that and of similar soils. Looking to the very various conditions of the different plots so differently treated, the interesting question suggests itself—whether, if each of them could be magnified into a farm of 100 acres,

with the history of its treatment attached to it, the purchasir or letting value would be different in the different cases?

It is quite certain that the most experienced land-valuer cou not detect any visible difference between the land which h grown wheat or barley for 25 years, or more, with superphospha of lime, and salts of potass, soda, and magnesia, and that whic has grown the same crop with salts of ammonia alone. H might, perhaps, observe a difference in the stubble, but th would be in favour of the plot exhausted of potass and pho phoric acid by the continual use of ammonia salts alone, rath than of that to which an excess of the mineral constituents ha every year been added without nitrogen. Compared with th land of neighbouring farms, the chief difference he would ol serve would be a marked freedom from weeds on the exper mental plots. For myself, after much consideration of th subject, I feel that I should have extreme difficulty in assignin a higher letting value to land corresponding in condition to tha of one plot rather than to that of another, or in fixing a differen rental from that of a similar land in the neighbourhood. A any rate, the difference would be but slight, and would b applicable for only a short period of time. The land in m immediate locality is not, as a rule, kept in high condition, no very clean; and I am disposed to think that the comparativ freedom from weeds of the more exhausted experimental land a Rothamsted would compensate for any loss of condition whic it may have sustained by the treatment to which it ha been exposed, and that I should give it the preference on tha account.

For my own information, and for that of the numerous agri culturists who visit Rothamsted every summer during th growth of the crops, I have grown many more corn crops i succession, by means of purchased manures, on most of the lan on my farm not under continual experiment, than I shoul think of doing if my only object were profitable farming, o

than could possibly be done by farmers generally; and I think the unanimous opinion of the many practical farmers who inspect the crops so growing at Rothamsted, would be that the land is surprisingly clean, and that there is no evidence of exhaustion such as they would expect to see under the circumstances.

The sources of supply, external to the farm itself, of nitrogen, phosphoric acid, and potass, may be briefly summarised as follows:—

Nitrogen.—The sources of supply of nitrogen, at present known, are more limited, in proportion to probable future requirements, than those of either phosphoric acid or potass. There are, however, vast deposits of nitrate of soda in Peru and Bolivia. Those in Bolivia have not as yet been worked. At present, the other supplies are more than equal the demand. A future generation of British farmers will, doubtless, hear with some surprise that, at the close of the manure season of 1876, there were 40,000 tons of nitrate of soda in our docks which could not find purchasers, although the price did not exceed £12 or £13 per ton. Peruvian guano, sulphate of ammonia, and soot, are manures which also supply large quantities of nitrogen. The consumption of purchased cattle foods is another large and increasing source of supply of nitrogen to our soils.

Phosphoric Acid.—The external sources of phosphoric acid, once limited to that in bones, are now very extensive; and the supplies of it from various mineral deposits throughout the world are quite equal to any demand for it that is likely to arise.

Potass.—Until within the last few years, the chief source of potass was wood ashes, and this supply would have been quite insufficient to meet any large demand for it for manure. The discovery, in Prussia and Anhalt, of vast deposits of salts of potass, mixed with salts of soda and magnesia, has greatly increased the supply, and lowered the price, of potass in the market. A company has recently been formed, which has acquired the

right to work extensive newly discovered deposits in Germany. From their prospectus it appears that the area of their concessions has already been proved to contain enough of crude potass salts to supply the whole of the arable land of Great Britain with very many tons per acre.

These large external sources of supply of nitrogen, phosphoric acid, and potass, which were unknown to a former generation of farmers, would afford the means of adequate restoration to the land under a very much less restrictive system, both as to cropping and sales of produce, than that which now prevails, and is considered essential for the maintenance of the fertility of our soils. It is generally supposed that larger quantities of both corn and meat are produced upon a given area of land in Great Britain than in any other country. With concentrated production, agriculture ceases to be a mere process of sowing and reaping. It becomes a process of manufacture, involving numerous complicated problems, for the solution of which the aid of science is necessary, and should be gladly welcomed. The importance of science to agriculture is, however, more fully recognised in several other countries than in our own. Even the farmers of the United States, who, with their vast area of virgin soil, are able to supply us with both corn and meat at prices which we find it difficult to contend against, have their *Journal of Scientific Agriculture*, and they are generally much better acquainted with the investigations in progress at the different agricultural stations on this side of the Atlantic than are our own farmers.

May we not attribute some of the indifference to the teaching of science, which is displayed by the British agriculturist, to the influence of the restrictive covenants under which he work May not the farmer argue, with some show of reason, that it useless to trouble himself about scientific principles, so long his landlord places a veto upon his application of them practice?

If it be true, as I said at the commencement, that the interests of the landowner and the tenant are intimately connected, and mutually dependent, rather than conflicting, and that the tenant cannot suffer loss, without injury, sooner or later, overtaking the landowner, the present time would seem to be very appropriate for considering whether the restrictions on cropping and sales might not, with advantage to both, be materially modified, or even in some cases entirely removed? The last few years have entailed serious losses upon the business of farming. Owing to cattle diseases, and other causes, the live-stock of the country has diminished. I have myself, for the last three years in succession, recorded in the *Times* a wheat crop much below the average; whilst, until quite recently, the price has been kept down by large imports. Further, there has been a considerable increase in the cost of labour, without a corresponding increase in its efficiency. All these unfavourable circumstances have pressed heavily upon farmers; and it is generally believed that an unusually large number of farms are just now thrown upon the hands of the landowner. It is to be feared that many tenants have been living upon their capital, and that it is only the fortunate few who have of late years been able to lay by any money.

I would not say that freedom of action as to cropping and sales would be a complete remedy for all these adverse circumstances; nor should I wish to see it granted indiscriminately. But I do not hesitate to say that, if I entered upon the business of farming to make money, I could not conduct it to the best advantage without such freedom. If there are many farmers who have too little knowledge and intelligence to comprehend the requirements of an improved system of agriculture, and too little capital to carry it out with success, there are, on the other hand, many who do possess both the requisite intelligence and the requisite capital. It is on their behalf that I would address the owners of the soil. But, in proposing the relaxation

or abandonment of long-established restrictions, I would not by any means assume that the tenant alone will reap the benefit. Not only the producer, but the consumer—the public at large —must derive advantage from an improved and more productive system of agriculture. Nor could these results follow without favourably re-acting upon the interests of the landowner.

Since restrictive covenants were first generally established great changes have taken place in almost every important element of the question involved. There have been changes in the actual and relative prices of the various products of the farm. There has been advance in our knowledge of the capability, and of the exhaustion, of soils, and in our knowledge of the action of manures. The sources of external supply of the most important constituents of manure have been vastly developed, and are capable of further development. All these changes point in one direction—in the direction of greater freedom in the cultivation of the soil, and of greater freedom in the sale of its products. Thirty years ago, it was believed that "protection" was necessary to keep up the value of the land of this country. Time has shown how fallacious was that belief. Is it not possible, or even probable, that the fears now entertained that the fertility of our soils, and their rental value cannot be kept up without the artificial protection of restrictive covenants, may prove to be equally groundless?

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[redacted]

IS HIGHER FARMING A REMEDY FOR LOWER PRICES?

BEING THE SUBSTANCE OF A LECTURE DELIVERED BEFORE THE EAST BERWICKSHIRE AGRICULTURAL ASSOCIATION, ON SATURDAY, MAY 3, 1879.

BY

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IS HIGHER FARMING A REMEDY FOR LOWER PRICES?

THERE can be no doubt in the minds of all present that British Agriculture is passing through a crisis of unusual severity. The complaints which farmers are accused of making, even in the best of times, spring from very different causes from those which we now hear of around us. Bad seasons, following each other in close succession, in a manner quite unusual even in the uncertain climate of these islands, have seriously reduced the produce of the land. Immense importations of corn have deprived the farmer of the higher prices which would otherwise have compensated him for his diminished crops. He pays a higher price for labour, frequently without any corresponding increase in its efficiency. Lastly, diseases among stock, the dread of future disease from imported animals, and the influence of importations of live stock and dead meat upon prices, present and prospective, have greatly increased his difficulties. For the moment his energies are paralysed, and he is led to inquire what he is to do next?

It need hardly be said that, under these circumstances, advice is not wanting. In fact, it is so abundantly offered, and is of such various kinds, that you must have some difficulty in selecting that which is most applicable to your own case. You are told to farm more scientifically, to meet lower prices by increased production, or to put a stop to music in your family circle! These are specimens of the numerous remedies proposed to enable you to meet the difficulties which at present surround *you, and still to carry on your farming operations with a profit.*

It will doubtless be some comfort to you, if I say at the commencement of my address, that I do not propose to add myself to the list of your advisers. I possess no specific against the combined effects of bad seasons, cheap corn, dear labour, and cheapening meat. You will gather from the title of my paper that my object is rather to assist you in examining into the applicability of one of the pieces of advice frequently offered to you; namely, that you should meet lower prices by increased production.

No one will deny that a great deal of the land of the country is badly farmed, or that it would be more profitable to raise more produce upon it. To what extent such is the case in Berwickshire I am unable to say. A reference to the Agricultural Statistics will, however, give us some idea of the general character of the cultivation of the county. I find that, in 1878, it comprised 193,622 acres of arable and pasture land, exclusive of heath or mountain land, and that this area was under different crops, as follows:—

	Per Cent.
Grain and pulse crops, ...	33
Green crops (excluding clover and grass), . .	18
Permanent grass, clover, &c., in rotation, for hay, .	5½
Do. Do. Do. not for hay, .	43½
	100

Thus, scarcely one-third is devoted to the growth of corn crops; and even if all the corn and potatoes grown, and all the hay made, were sold off the farm, the produce of scarcely 40 acres in every 100 would be sold, leaving 60 for consumption by stock for the production of meat and manure, the latter to be retained on the land. But we know how wide of the truth it is to assume that all the hay and oats grown are sold; and we have at the same time to bear in mind, that the straw grown on the 33 per cent. of land which is devoted to corn, will for the most part be retained on the farm. If, in addition to these facts, we were to take into account the cattle foods and manures purchased and brought on to the land, I think we should have abundant evidence that Berwickshire is, upon the whole, a highly farmed county; and *if a certain* proportion is badly farmed, we may conclude that *the remainder* is in a high state of cultivation.

It is to those in this county who do already farm highly that my remarks are chiefly applicable; but they will apply also to high farming generally, wherever it may be practised. No one, I suppose, can doubt that the soils of this country are capable of producing very much more wheat and meat than they do at present, if not, indeed, all that is required to support the population. If imports of these articles were prohibited, or a heavy duty imposed upon them, there is no doubt that a much higher system of farming would be profitable than at present prevails. In such a case, however, our dependence on the produce of foreign soils would not be lessened. The increased production of wheat and meat here supposed could only be attained by increased imports of cattle foods and manures. The countries which now supply us with wheat and meat would supply instead such products as they were permitted to sell to us. Our dependence on the foreigner would therefore be equally great; the only difference would be that it would be for other commodities than at present.

Our subject is not, however, what should be done if wheat and meat were to advance in price; but whether a higher standard of farming can be recommended to compensate for a reduction in price. To put the matter plainly:—supposing there were a permanent reduction in the price of the saleable produce of the farm to the extent of 20 per cent., would the proper remedy be to increase our produce per acre by one-fourth, and so to bring up the saleable value to the same amount as before?

There can be but little difference of opinion as to what is to be understood by the term "high farming." It is certainly not high farming that produces the wheat which is now selling at so low a price in our markets. When we read in the United States papers that in one year 20,000,000 acres of land had been purchased for cultivation, and that within ten years 10,000,000 acres had been added to the area under wheat alone, it will be at once understood that it is what is called *extensive* as distinguished from *intensive*, or high farming, that has yielded the supplies we receive. Nor can there be any doubt as to one main cause at least, of the present depression. Farming on the four-course system, consuming

each alternate crop on the farm, and, in addition to this, converting all the straw of the corn crops into manure, but without the use of purchased foods or manures, would not constitute high farming.

High farming is a very different process. It implies the importation of material from without. All soils are capable of yielding more or less annually from their own substance to the produce which grows upon them. But, the greater the amount of cattle-food and manure purchased and brought upon the land—that is, the higher the farming—the less will the soil itself contribute to the crops. Indeed, in many cases, it contributes nothing at all, but becomes richer by the process. Under such circumstances, the soil may be said to serve mainly as a reservoir for the manures applied, and for the necessary moisture, and to afford support to the growing plants; so that, with the aid of the sun's rays, they may be enabled to accumulate carbon (and other constituents) from the atmosphere. They thus, so to speak, manufacture raw material supplied from external sources. Under such conditions agriculture is a manufacture depending on the products of other soils, and on the atmosphere, for its raw material, just as much as do the manufactures of wool, cotton, and silk depend on external sources for their material.

Adopting the foregoing description of high farming, we have next to inquire whether those who already practise i should carry it out still further, as a means of compensatio for a lower standard of prices of corn and meat?

Before any answer can be given to this question, it will necessary carefully to consider what are the various sourc the effects, and the cost of manures.

Many of the charges connected with farming are much same whatever may be the value of the crops grown. course, harvesting a large crop of corn costs something n for labour than harvesting a small one, and the expenses heavy crop of roots will also be somewhat more than light one. Still, it may be said that, with the exceptio the extra cost of the manure required to grow the larger the charges remain very much the same whether the am and the value, of the produce be great or small. If, the the increase in the produce bore a constant proportion

increase in the amount, and consequently the cost, of the manure applied—if, in fact, the application of two or three times as much manure yielded twice or thrice as much increase of crop—then higher farming would be a remedy for lower prices. But such is not the case. It may, it is true, be said that, as the produce increases, the proportion of the fixed expenses to be charged upon a given amount of it diminishes, thus tending to compensate for the less productiveness of a given amount of manure the greater the quantity of it applied. But a very little consideration of the facts I propose to bring before you would show that, with increased production beyond a certain limit, the cost of the manure for a given amount of increase increases very much more rapidly than the proportion of the fixed expenses diminishes.

Nowhere are the extremes of farming better illustrated, and nowhere can they be better studied, than in the results of the field experiments at Rothamsted. Nowhere else are various crops grown for a great many years in succession, in some cases without any manure at all, so as to tax the capability of the soil itself to the utmost, and in others with very liberal supplies, either of farmyard manure or of artificial manures, so as to enrich it as much as possible. So liberal, indeed, has been the application of farmyard manure in some of the experiments, that a critic, who apparently did not quite understand their object, was reported in the *North British Agriculturist* to have said that we seemed to have a spite against farmyard manure, as he considered that much smaller applications would have produced as much effect.

I propose now to call your attention to some of the field experiments in question, the results of which will prove that, beyond a certain limit, the increase of crop is not in proportion to the increase in the amount of manure applied. In other words, that the higher you farm beyond a certain limit, the less is the amount of increase you obtain for a given amount of manure, and, therefore, the greater the cost of that increase. If this be the case, it is obvious that the cost of manure is a very important subject for consideration.

It is frequently assumed that the manure made by feeding stock costs nothing; that by skilful and judicious management, the cost of the food, and the other expenses, will be

covered by the value of the meat produced and sold; and that, this being so, the manure is obtained gratis. I shall, therefore, occupy a portion of the time at my disposal in illustration of the fact that the food of an animal will, as a rule, cost more than the meat produced will sell for; and that, consequently, the cost of the food, and the other necessary expenses, can only be recovered by charging a portion to the manure.

To commence with the field experiments. I shall first call your attention to some of the results of some experiments on an ordinary rotation of crops, which are now in the thirty-second year of their progress. The arrangement of them is in reality very simple; though, from their number, it will require a little attention fully to comprehend the plan.

Experiments on Rotation.

The ordinary four-course rotation of turnips, barley, clover or beans, and wheat, has been adopted; and the eighth crop of wheat, that is to say, the last crop of the eighth course, is now growing. In the first course, a large crop of clover, which was mown three times, was obtained. In the second and third courses, red clover was again sown, but it failed each time, and beans were then put in instead. Beans were also grown in the fourth, fifth, sixth, and eighth courses; but in the seventh, red clover was again tried, and it grew successfully, again yielding three cuttings. We have had, therefore, eight crops of roots, eight of barley, six of beans, two of red clover, and seven of wheat; the eighth of this last crop being now growing.

Such being the course of cropping, I will now explain the system adopted as to manure.

One-third of the land has been kept entirely without manure throughout the whole period of the experiments.

One-third has received mineral superphosphate of lime alone, every fourth year, that is for the root crops.

The other third has received, also every fourth year only, that is for the roots commencing each course, a very liberal artificial mixture, composed as follows:[1]—

[1] For the first course, only 1000 lbs. rape cake instead of 2000 lbs., as always afterwards, were applied. In the first and second courses less superphosphate, and in the first course less potass, and no soda or magnesia, was used.

	Per Acre.
Rape cake, ...	2000 lbs.
Sulphate ammonia, ...	100 lbs.
Muriate ammonia, ...	100 lbs.
Sulphate of potass, ...	300 lbs.
Sulphate of soda, ...	200 lbs.
Sulphate of magnesia, ...	100 lbs.
Superphosphate of lime, ...	350 lbs.

This mixture I shall speak of as the *Complex Manure.*

Next as to the treatment of the crops:—

Each of the three portions, so differently treated as to manure, has been divided into two experiments. From one half, the whole of the produce, roots and tops, corn and straw, and clover, has been removed. On the other half of each, the only difference has been, that the roots were fed on the land by sheep having no other food, and the tops were also left on the land.

We have, therefore, three experiments in which the whole of the produce has been carried away for thirty-one years in succession; on one without any manure having been applied; on another with mineral superphosphate of lime alone, applied to the roots, that is every fourth year; and on the third with a very heavy artificial manuring, also for the roots only. We have also three exactly parallel experiments with the roots fed upon the land by sheep instead of being carted away.

I may mention that there is another series of six experiments, corresponding in every respect with those the results of which are given in the Tables, with the exception that bare fallow, instead of either beans or clover, has been taken between the barley and the wheat in each course since the first, when clover was taken. I do not propose to refer to this last set of experiments on the present occasion, as to do so would lead me away from my subject; but I may observe that the comparison between a rotation with clover or beans, and one with bare fallow, presents many points of interest.

I will now call attention to the results obtained in these Rotation Experiments. In Table I. is given the produce of roots, of corn, and of clover hay, and to this I shall confine my remarks. But, for the information of those who may wish to study the subject further, there are given in Table II. the amounts of the "Swede-tops" and of the straw also.

TABLE I

EXPERIMENTS ON FOUR-COURSE ROTATION, AT ROTHAMSTE

***Summary:—Average Produce of Roots, Corn, and Clover H Eight Courses,* 1848-1879.**

		Roots Carted.	Root Fed.
Roots—Swedes, 7 crops, 1848, 1852, 1856, 1860, 1864, (1868 failed), 1872, 1876.		Tons.	Ton.
Unmanured, continuously,		1¼	1¼
Superphosphate, for Roots only,		7½	8¼
Complex Manure, for Roots only,		13¾	13¾
Barley Grain, 8 crops; 1849, 1853, 1857, 1861, 1865, 1869, 1873, 1877.		Bushels.	Bushe
Unmanured, continuously,		35	30¼
Superphosphate, for Roots only,		28¼	39¾
Complex Manure, for Roots only,		41¾	46¾
Bean Corn, 6 crops; 1854, 1858, 1862, 1866, 1870, 1878.		Bushels.	Bush
Unmanured, continuously,		12½	17
Superphosphate, for Roots only,		12¾	1
Complex Manure, for Roots only,		21½	2
Clover, 1850 and 1874. (Calculated as Hay.)		Cwts.	C
Unmanured, continuously,	1850,	54	
	1874,	31¾	
	Mean,	42⅞	
Superphosphate, for Roots only,	1850,	57¾	
	1874,	52¼	
	Mean,	55	
Complex Manure, for Roots only,	1850,	63	
	1874,	84¼	
	Mean,	73⅝	
Wheat Grain, 7 crops; 1851, 1855, 1859, 1863, 1867, 1871, 1875.		Bushels.	
Unmanured, continuously,		30	
... for Roots only,		29¼	
... only,		33¾	

TABLE II.

EXPERIMENTS ON FOUR-COURSE ROTATION, AT ROTHAMSTED.

Summary:—Average Produce of Swede-Tops and of Straw; Eight Courses, 1848–1879.

	Roots Carted.	Roots Fed.
Swede-Tops, 7 crops; 1848, 1852, 1856, 1860, 1864, (1868 failed), 1872, 1876.	Tons.	Tons.
Unmanured, continuously, ...	½	½
Superphosphate, for Roots only, ...	1⅜	1¼
Complex Manure, for Roots only,. . . .	2⅛	2⅛
Barley Straw, 8 crops; 1849, 1853, 1857, 1861, 1865, 1869, 1873, 1877.	Cwts.	Cwts.
Unmanured, continuously, ...	19¼	17⅝
Superphosphate, for Roots only, ...	15½	22⅛
Complex Manure, for Roots only,. . . .	23	28¾
Bean Straw, 6 crops; 1854, 1858, 1862, 1866, 1870, 1878.	Cwts.	Cwts.
Unmanured, continuously, ...	9⅝	9⅛
Superphosphate, for Roots only, ...	10¾	13¼
Complex Manure, for Roots only,. . . .	16⅛	16⅞
Wheat Straw, 7 crops; 1851, 1855, 1859, 1863, 1867, 1871, 1875.	Cwts.	Cwts.
Unmanured, continuously, ...	28	25½
Superphosphate, for Roots only, ...	29	32⅜
Complex Manure, for Roots only,. . . .	35⅝	35⅝

In the upper division of Table I. you have the average produce of roots per course, over seven courses (one failing), under each of the three conditions as to manure, and both on the carted and on the fed portions of the land. You will observe that, without manure, there was practically no crop of roots at all. The swedes which grew did not represent the cultivated root you are accustomed to see, either in size, form, or composition. Mineral superphosphate of lime, alone, increased the crop considerably, giving an average of between 7 and 8 tons of roots. The complex manure gave an average of

about 5 tons more, raising the crop to about 13 tons. You will observe that, under neither condition as to manuring was there any material difference in the succeeding crop of roots grown on the portion from which they had previously been carted, as compared with that on which they had always been fed. It is to be concluded, therefore, that the manure left on the land by the sheep, was either taken up by the intermediate crops, lost by drainage, or remained in the land in a condition not available for the next crop of roots.

There being practically no crop of roots to carry away from the unmanured land, and as little to be fed on the land, we should naturally expect scarcely any difference in the amounts of the crops subsequently grown on the two portions of unmanured land. We find, however, a considerable difference, there being an average of more than 4 bushels of barley in favour of the portion from which the roots were carted, as compared with that on which they were fed. It is quite certain that this anomalous result is not due to any want of care in the conduct of the experiments. It may, I think, safely be attributed to a slight but unfortunate difference in the character of the land. In the present state of our knowledge on such subjects, considerable caution is necessary in attempting to trace a connection between the fertility of a soil and its composition as shown by analysis. Still, I may mention that, at two periods, with an interval of seven years between, samples of the first 9 inches, the second 9 inches, and the third 9 inches, or to a total depth of 27 inches, have been taken from each of the separate plots of land; and, on each occasion, analysis has shown a marked superiority in the land from which the roots are carted, and which has yielded the largest crops of both barley and wheat; and the superiority is the more marked in the second and third than in the top 9 inches of soil.

You will doubtless notice with some surprise that so much barley was grown on land in a condition incapable of growing even a moderate crop of roots. From 4 to 4½ quarters of barley is probably as much as the average yield of that crop in Great Britain. On this point it should be borne in mind, that as nothing was removed in the preceding root crop, the land was, to all intents and purposes, fallowed for the barley.

It will be seen, further on, however, that the wheat crop growing in this permanently unmanured rotation, also approached very closely to the average yield of that crop over the country at large.

Upon the land manured with mineral superphosphate for the Swedes, the removal of about 8 tons of roots (and the tops) has reduced the produce of barley to 28¼ bushels, or to nearly 3 bushels less than the lowest unmanured produce; whilst the consumption of the Swedes on the land has raised the produce to nearly 40 bushels. The exhaustion of the soil by the removal of the roots is thus equal to the loss of more than 11½ bushels of barley.

Turning to the complex manure plots, it will be seen that, although from the portion from which the roots were carted a much larger quantity was removed than from the corresponding portion of the superphosphate plots, still the crop of barley was very much greater. It was, in fact, about 13½ bushels more than where the superphosphate roots were removed, and even from 1 to 2 bushels more than where the superphosphate roots were consumed upon the land.

The explanation of this is not far to seek. The superphosphate supplied no nitrogen, but it enabled the root crop to gather up a quantity already accumulated within the soil itself. The available stock within the soil of this important substance was so far drawn upon by the removal of the 8 tons of roots, and their tops, that the succeeding crop of barley was much reduced. In the rape-cake and ammonia salts of the complex manure, on the other hand, from 130 to 140 lbs. of nitrogen were supplied, and this is very much more than was removed in the 13 tons of roots grown by it. There was, therefore, a considerable residue of that supplied in the manure available for the succeeding barley crop, which was, accordingly, raised to 41½ bushels.

The consumption on the land of the Swedes grown by the complex manure has added only about 5¼ bushels more. Nevertheless, it is certain that by far the larger proportion of the nitrogen, and other constituents, derived from the *soil* by a crop of roots, is returned to it when they are consumed by animals on the land; whilst, of those constituents which are derived by the plant from the atmo-

sphere, by far the larger proportion is returned to the atmosphere by the animals.

It is obvious that, in this experiment, where the highly manured roots were fed on the land, compared with that where they were drawn off, we have, so far as the succeeding barley is concerned, an instance of high farming, without a corresponding return in the amount of produce.

Turning to the bean crops, it will be observed that, both on the unmanured and the superphosphate plots, they are very small. On the unmanured plots there is practically no difference between where the roots had been carted and where they had been fed. On the superphosphate plot the crop of beans was rather higher where the roots had been fed. On the complex manure plots the crop of beans was considerably higher; being about 22 bushels where the roots had been carted, and about 24½ bushels where they had been fed. This is rather more than double the amount obtained without manure. The difference, or 12 bushels, is, therefore, due to the residue of the manures left after the removal of the barley.

The difference in the amounts of produce of the two crops of clover is exceedingly interesting. Between 1850, when the first, and 1874, when the second crop of clover was taken, six crops of wheat, six crops of barley, and five crops of beans had been removed from the whole of the plots, and from one-half of them five crops of roots in addition.

On the unmanured plots about 1 ton less hay was grown per acre in 1874 than 24 years previously. On the superphosphate plots the second clover crop was slightly lower than the first where the roots (as well as all the other intermediate crops) had been removed; but it was in a greater degree higher where the roots had been consumed on the land. It is remarkable that, although the intermediate crops removed considerably more nitrogen, and also more of other constituents, from the superphosphate than from the unmanured plots, the superphosphate plots should still yield a much higher crop of clover at the second period. I am disposed to think that this is due, in part at least, to the gypsum contained in the superphosphate, but probably partly also to the reactions of the superphosphate in liberating other constituents within the soil.

On the complex manure plots the clover crop of the first course was considerably higher than that on either of the other plots, and the later crop, that of 1874, was about 1 ton more than the earlier one, on both the carted and the fed portions. Comparing the highest crop with the complex manure with the lowest without manure, there is a difference of nearly 3 tons more clover hay where the land was in the much higher condition. Since the commencement of the experiments there had been seven, and since the previous clover crop in 1850 there had been six, applications of the complex manure; and although a large proportion of the nitrogen supplied in it is accounted for in the increase of produce removed, a large amount still remained unaccounted for. It is seen, therefore, that an important effect of the red clover is to gather up the residue of manure which none of the other crops in the rotation had been able to do. It is considered a great desideratum to grow red clover as frequently as possible; but it is obvious that the crops must be small, or fail altogether, if it be attempted to grow it when there is not a sufficient accumulated residue of the proper manurial constituents available within the soil.

In the lowest division of the Table the average produce of the seven wheat crops is given. You will observe that there is exactly the same difference between the produce of the two unmanured portions as in the case of the barley, namely, 4 bushels; and that the lowest amount is again where the roots were fed on the land. This result affords further confirmation of the supposition that there was a difference in the character of the soil of the two plots. The average produce of the two unmanured plots is 28 bushels of wheat, and it was 33 bushels of barley. Thus, we have the remarkable fact, as already alluded to, that upon land entirely unmanured for 31 years the crops of barley and of wheat grown in the rotation have very nearly corresponded with the average yield of those crops in the United Kingdom.

The crops of wheat on the superphosphate and on the complex manure plots do not differ very much. They are higher where the superphosphate roots were fed than where they were carted; and they are rather higher still on both the complex manure plots, but identical on the two plots so manured, from

one of which the roots were carted, whilst on the other they were fed.

I think you will agree with me in thinking that the result of this high farming, where the highly manured roots were fed upon the land, is somewhat disappointing; and that to farm still higher, as prices fall, would be a mistake.

I have long ago satisfied myself that the four-course rotation, and the feeding of roots upon the land, or even the growth of turnips at all, is quite unsuitable on the soil and with the climate of Rothamsted. We have learnt much respecting the action of manures, the requirements of different crops, and the influence of climate upon them, during the many years of the progress of our field experiments, and among other things, that we can gather up much more of the manure applied, by means of a mangold than of a turnip crop.

Experiments with Farmyard Manure.

I will now bring before you some experiments in which farm-yard manure has been applied many years in succession to different crops. When you are urged to farm higher, the meaning is that you should put more dung upon your land. Consequently, it is of great importance to ascertain, with as much accuracy as possible, the effects of the application of large quantities of dung.

In Table III. is given the produce of wheat, grain and straw, and of barley, grain and straw, by the application of 14 tons of farmyard manure per acre per annum. In the upper division of the Table the results obtained with wheat, and in the lower those obtained with barley, are recorded. The experiments on wheat have now been continued for 35 years, and the average produce per acre per annum is given for the first 8 years, the next 9 years, the next 9 years, and the last 9 years. The experiments on barley have been continued for 27 years, and the results are given for the three periods of 9 years each, corresponding with the last three periods in the case of the wheat.

TABLE III.

PRODUCE OF WHEAT AND OF BARLEY, BY 14 TONS FARMYARD MANURE PER ACRE, EVERY YEAR.

	Average per acre per annum.	
	Dressed Corn.	Straw.
Wheat, year after year on the same land— *35 years*, 1844–1878.	Bushels.	Cwts.
First Period, 8 years, 1844–1851, . . .	28	26⅝
Second Period, 9 years, 1852–1860, . . .	34⅛	34⅝
Third Period, 9 years, 1861–1869, . . .	37⅛	33⅝
Fourth Period, 9 years, 1870–1878, . . .	31	29⅞
Barley, year after year on the same land— *27 years*, 1852–1878.		
First Period, 9 years, 1852–1860, . . .	44	26
Second Period, 9 years, 1861–1869, . . .	52	30⅜
Third Period, 9 years, 1870–1878, . . .	49¾	29⅝

Referring first to the wheat, you will observe that the average produce of the first 8 years is the lowest, that of the next 9 years is higher, that of the third period is higher still, and that of the last 9 years again considerably lower; being only about 3 bushels more than over the first period, about 3 bushels less than over the second, and 6 bushels less than over the third period.

It is quite obvious from this result, that the produce was not at all in proportion to the accumulation of manure in the land. When the soil was analysed a few years ago, it was found that the first 9 inches in depth was nearly twice as rich in nitrogen as that of any of the artifically manured plots, yielding as much, or even more, produce. There can be no doubt that, whilst there is a general tendency to increase in produce as the result of this great accumulation of manure in the soil, the fluctuations are greatly dependent on the characters of the seasons. Thus, the third period, which gives the highest produce, included some very productive years, whilst the fourth period included a number of bad seasons, the adverse influence of which, the constantly increasing

accumulation of manure within the soil only very partially obviated. It will be observed, too, that the amount of straw, the excess of which is a sure sign of excess of manure and over luxuriance, upon the whole increases rather less than that of the corn; there being less straw over the third period, with the highest produce of corn, than over the second with a lower produce of corn; whilst the fourth period gives considerably less than either the second or the third. This is the more remarkable, since the annual application of 14 tons of dung will have annually brought upon the land the equivalent of from 3 to 4 tons of straw. The fluctuations in the produce of straw, as well as in that of the corn, further illustrate the influence of season in spite of the accumulation of manure.

Turning to the experiments with barley, we have, upon the whole, very accordant results over the three periods, compared with the same three periods with wheat. Thus, the last period but one, which included a number of very good seasons, gave more produce than the last period, notwithstanding the greater accumulation of manure in the later years. There is in the barley, too, as with the wheat, no striking increase in the production of straw; for although there was considerable variation in the proportion of corn to straw in individual years, according to season, the average proportion is almost identical for each of the three periods.

It is then obvious, that there is no increase of produce, of either wheat or barley, over the later years, at all commensurate with the increased accumulation of manure in the soil.

You will doubtless be interested to know something of the after effects of these great accumulations of dung in the soil, seeing that they increase the crops so inadequately during the period of the application of the manure.

Table IV. affords some information on this point. The two upper divisions relate to barley, and the lower one to meadow hay. After 14 tons of farmyard manure had been applied for 20 years in succession on one plot in the field devoted to the continuous growth of barley, the plot was divided. On one-half the annual application of the dung has been continued, now for a period of 7 years more; whilst the other half has *been left* unmanured, also now for 7 years. In the experi-

ments on meadow hay, the application of 14 tons of farmyard manure per acre per annum was continued for 8 years; and the land has since been left unmanured for 15 years. The Table shows the produce of barley, corn and straw, and of hay, during the periods of the application of the dung, and after the cessation of the application. It also shows the increase over the continuously unmanured produce over the respective periods.

TABLE IV.

SHOWING THE EFFECTS OF THE UNEXHAUSTED RESIDUE OF FARMYARD MANURE.

	Average per acre per annum.	
	Produce.	Increase over continuously unmanured.
Barley Grain.	Bushels.	Bushels.
20 years, 1852–1871, 14 tons farmyard manure every year	48¼	28¼
7 years, 1872–1878, 14 tons farmyard manure every year	49½	36
7 years, 1872–1878, unmanured, after 20 years farmyard manure	36¼	22¾
Barley Straw.	Cwts.	Cwts.
20 years, 1852–1871, 14 tons farmyard manure every year	28¼	16½
7 years, 1872–1878, 14 tons farmyard manure every year	29⅞	23
7 years, 1872–1878, unmanured, after 20 years farmyard manure	20¼	13⅝
Meadow Hay.		
14 tons farmyard manure every year, 8 years, 1856–1863	42⅞	19⅛
Afterwards unmanured: 5 years, 1864–1868	40⅞	19⅝
Afterwards unmanured: 5 years, 1869–1873	29⅜	10⅛
Afterwards unmanured: 5 years, 1874–1878	23¼	6¾

It will be seen that there is an average of only 1¼ bushel of barley grain and 1¾ cwts. of straw, per acre per annum, more *over the last 7 years* than over the first 20 years, where

the application of the dung was continued. Where the dung was discontinued after 20 years, the produce of corn was, over the next 7 years, not quite three-fourths as much, and that of the straw but little over two-thirds as much, as where it was continued. The average annual deficiency was 13¼ bushels of corn, and 9½ cwts. of straw. Compared with the continuously unmanured produce over the same periods (which, however, declined considerably over the later years) it is seen that the annually applied dung gave an average increase, over the first 20 years of 28¼ bushels of corn and 16½ cwts. of straw, and over the last 7 years of 36 bushels of corn and 23 cwts. of straw. And where the dung was discontinued over the last 7 years, there was an average increase of nearly 23 bushels of grain and 13½ cwts. of straw over the continuously unmanured produce. In the last year of the seven, 1878, the plot where the application of dung was continued gave 36¼ bushels of corn and nearly 26½ cwts. of straw more than the unmanured plot; and the plot where the dung was discontinued gave, in the same or seventh year of the discontinuance, nearly 12 bushels of corn, and nearly 10¼ cwts. of straw, more than the unmanured. It is obvious, therefore, that the residue of the 20 years application of dung is still yielding increase. It is, however, gradually declining. But there is no doubt that the residue will continue to be effective in a still more declining ratio for many years to come. It would, indeed, take considerably more than a century at the present rate to recover in increase of produce all the nitrogen of the manure which has not yet been so recovered.

Turning now to the results obtained with meadow-hay, as already stated, 14 tons of farmyard manure were applied per acre annually for 8 years in succession, and the produce has since been taken for 15 years without manure. The Table shows the average annual produce and increase of hay over the 8 years of the application, and over the first 5, the second 5, and the third 5 years afterwards. It will be observed that over the 8 years of the application the average produce of hay was nearly 2 tons 3 cwts.; and the average increase over the continuously unmanured produce was not quite 1 ton. *Over the first 5 years after the cessation of the application, the average produce* was about 2 cwts. less; but, substantially,

both produce and increase averaged much about the same as over the 8 years of the application. Over the second 5 years, the produce diminished to less than three-fourths as much as over the first 5, and the increase was little over 10 cwts. of hay per acre per annum. During the last 5 of the 15 years, the produce was little more than half as much as its original amount, and the increase over the unmanured produce of the same period was not quite 7 cwts.

During the 8 years of the application of the dung there were obtained, in all, 17 tons 3 cwts. of hay, corresponding to 7 tons 13 cwts. of increase; over the next 15 years there were obtained 23 tons 7½ cwts., corresponding to 9 tons 2½ cwts. of increase, due to the residue of the previously applied dung. Here, as in the case of the barley, it would require very many years to recover anything like the whole of the yet unrecovered residue of the previously applied nitrogen of the farmyard manure.

Looking to such results as the above, relating to barley and to meadow hay, it is not difficult to understand why a tenant who has been farming highly for a number of years should endeavour to get out some of the residue of the manure which he has accumulated in the land before he leaves it. But if so small a proportion of the constituents of the manure is recovered in the increase of crop during the years of the application when dung is very liberally used, it is not so evident that higher farming, which means more dung, should be a remedy for lower prices. Nor can I understand why the so-called "lasting" effects of dung should be considered such a merit. The Rothamsted experiments with various crops agree in showing, that a given amount of constituents supplied in dung does less work, and takes a longer time to do it, than when supplied in any other form.

Experiments with Artificial Manures.

The next illustrations will show the comparative effects of moderate and of large amounts of artificial manures. In the upper division of Table V. we have the average produce of wheat, both corn and straw, over 27 years—by a complex *mineral manure used alone*; by the same mineral manure and

200 lbs. ammonia salts; by the same and 400 lbs.; and by the same and 600 lbs. ammonia salts. In the lower division of the Table is given the average produce of barley over 6 years—with supherphosphate of lime alone; with superphosphate and 200 lbs.; and with superphosphate and 400 lbs. ammonia salts.

TABLE V.

SHOWING THE EFFECTS OF MODERATE AND OF LARGE AMOUNTS OF AMMONIA SALTS.

	Average per acre per annum.	
	Dressed Corn.	Straw.
Wheat every year, 27 years, 1852–1878.	Bushels.	Cwts.
Complex mineral manure, alone, ...	15¾	13½
Complex mineral manure, and 200 lbs. ammonia-salts,	24½	22¾
Complex mineral manure, and 400 lbs. ammonia-salts,	33¼	33¾
Complex mineral manure, and 600 lbs. ammonia-salts,	36¾	40⅜
Barley every year, 6 years, 1852–1857.		
Superphosphate, alone, ...	31⅛	16½
Superphosphate, and 200 lbs. ammonia-salts, . .	45½	28⅜
Superphosphate, and 400 lbs. ammonia-salts, . .	49⅝	34

Referring first to the wheat, it will be observed that by the addition of 200 lbs. of ammonia-salts per acre per annum to the mineral manure, an average increase of nearly 9 bushels of grain is obtained. By the addition of a second 200 lbs., in all 400 lbs. of ammonia-salts, there is a further increase of the same amount, that is, nearly 9 bushels. By the addition of a third 200 lbs., in all 600 lbs. of ammonia-salts, there is a further increase of only 3½, instead of 9 bushels. In like manner the first 200 lbs. of ammonia-salts give 9¼, the second 11, and the third only about 6½ cwts. increase of straw. Now, assuming that the application of 400 lbs. of ammonia-salts was the limit of high farming with profit with wheat at 6s. per *bushel, I cannot* see how it could be maintained that a further

200 lbs., yielding little more than a third as much increase as when used in more moderate quantity, should be employed because the price of wheat was reduced to 5s. per bushel. On the contrary, the conclusion I should draw from the results of these experiments is, that the application of the 600 lbs. of ammonia-salts could only be profitable if the price of wheat were to rise instead of to fall.

Again, it will be seen that in the case of the barley, the addition to superphosphate of lime, of 200 lbs. of ammonia-salts gave an average increase of nearly 14 bushels, whilst by the addition of a second 200 lbs., in all 400 lbs. of ammonia-salts, a further increase of little more than 4 bushels was obtained. It will be observed, however, that whilst with the increase of 14 bushels of grain there was an increase of only 12 cwts. of straw, there was with the further increase of 4 bushels of grain an increase of 5½ cwts. of straw, or a much larger proportion of straw to corn in the increase by the second than in that by the first 200 lbs. of ammonia-salts. It was, in fact, so evident from the bulk, and the laying of the crop, that 400 lbs. of ammonia-salts was an excessive application, that, after its use for 6 years, the experiment was abandoned. Here, again, I think it must be evident that it would be higher, and not lower prices, that would justify the higher standard of farming.

From the various results which I have laid before you, you will have gathered that when farmyard manure is used, and even, though in a less degree, when manure is deposited on the land by animals feeding upon it, there is less immediate increase for a given amount of constituents supplied, and more accumulation within the soil, than when certain artificial manures are employed. You must not suppose that, in bringing this fact prominently to your notice, I wish in any degree to depreciate the importance of, so to speak, natural manures, and to exalt that of artificial manures. The production, and the use, of farmyard manure, are a necessity of the general economy of a farm; and there must be the more of it produced, or at any rate the more of animal manures, the greater the amount of meat produced. Nor would it be *possible to rely mainly* on artificial manures. I do think,

however, that farmers generally do not sufficiently recognise the slowness of the action of the natural manures of the farm; and that, so far as they do so, they frequently even look upon it as a merit rather than otherwise, that it should be as they say, more "lasting." But slowness of action means slowness of return for the outlay; and this will be the greater the more excessive the amount of the manure applied. In my opinion, the object to be attained, and that which I have no doubt will characterise the most successful farming of the future, is to get as quick a return as possible for the outlay in manures, whether natural or artificial. This can only be fully accomplished—with freedom in the growth and sale of that produce which is the most profitable, the selection of the crops which are the most suitable to the soils and seasons of the locality and the demands of the market, and such a judicious adaptation of natural and artificial manures to the crops to be grown, as to obtain the maximum increase of produce, with the minimum residue left unproductive in the soil, and subject to loss by drainage, and in other ways.

To sum up in regard to this first branch of my subject:—It has been shown by reference to the results of experiments on an ordinary four-course rotation with different manures, in some cases carting off the roots, and in others consuming them on the land, that, beyond a certain limit, the increase of produce was not commensurate with the increase in the amount of manure accumulated within the soil. The next illustrations showed that, when farmyard manure was used in excessive amount, for the direct growth of either wheat or barley, the increase of produce by no means corresponded with the accumulation of manurial constituents within the soil; that, notwithstanding an increasing accumulation from year to year, the crops even diminished in the later years under the influence of bad seasons, the increased amount of manure in the soil not fully compensating for the adverse influences of the seasons; and lastly, that the unexhausted residue of the previously applied dung, though yielding a considerable increase for many years afterwards, did so in a rapidly decreasing ratio, and only in such proportion that it would take *very many* years to recover the manure applied; even if, which *cannot* be supposed, it were ever fully recovered. In like-

manner it has been shown, that when artificial nitrogenous manures were used in gradually increasing amounts, the amount of increase obtained for a given amount of manure employed, very greatly diminished when the quantity applied exceeded a certain limit, which may be called the standard of high farming; so that, a given quantity of further increase was obtained only at a greatly increased proportional cost for manure.

The general and uniform result of the whole is, that, whether we go from high to still higher farming with an ordinary rotation of crops, with large amounts of farmyard manure applied year after year for the growth of corn, or with artificial manures in gradually increasing amounts, less increase of produce is obtained for a given amount of manure applied, the greater the excess of it over what may be termed the standard of moderate high farming. I leave you to judge whether, under such circumstances, the advance from high to still higher farming is likely to compensate you for lower prices of your produce.

The Manure produced by the Animals of the Farm.

I now come to the second branch of my subject, namely, the cost of the manure produced upon the farm. It may perhaps be assumed that, in the case of the horses working upon the farm, their labour may be taken as an equivalent for the cost of their food, the expenses of attendance, &c., and that the manure they produce is, so far, obtained free of cost. In the case of the feeding of animals for the production of meat, store stock may be cheap and fat stock dear, or *vice versa*, cattle food may be cheap and meat dear, and so on. In considering therefore whether, as a rule, the value of the meat produced is more or less than the cost of the food of the animal, together with the other expenses, it will be necessary to exclude from the calculation all such exceptional cases as above referred to; to take as the basis of any conclusions (so far as we can estimate it) only the average amount of food required to produce a given weight of increase; and to compare the cost of such food, and other expenses, with the value of the increase. Looking at the subject from this point of view, I think it will be found that the outlay is generally

much in excess of the receipts; and that there is, therefore, a balance left over which must be reckoned as the cost of the manure.

Confining my attention to cattle, I shall first endeavour to show, by reference to published records relating to animals of certainly above average quality, and undoubtedly liberally fed, what is the probable rate of increase that may be expected in such cases; and secondly, what is the average amount of food required to produce a given amount of increase.

In Table VI. are given, the ages, weights, and increase—first, of a number of prize cattle exhibited at Smithfield, in December 1878, as recorded in the *Agricultural Gazette* of January 13, 1879; secondly, of a number of prize cattle exhibited at the Chicago Society's Show (United States), and reported in the *Country Gentleman's Newspaper*; thirdly, of some French cattle of the Nivernais-Charolais breed, the particulars of which will be found in the *Journal of the Royal Agricultural Society of England*, vol. xv. p. 213; lastly, at the foot of the Table is given, for comparison, the estimate of the average rate of increase during the fattening period, as adopted at Rothamsted many years ago.

TABLE VI.

Ages, Weights, and Increase of Cattle.

Description.			Average Age.	Average Final Weight per head.	Increase per Day.	Increase per 1000 lbs. Live-weight per Week.
	No. of Class.	No. in Class.				
Prize Cattle at Smithfield, 1878.			Week	lbs.	lbs.	lbs.
Devons, . . .	1	9	116	1301	1·60	14·8
	2	7	167	1568	1·34	10·5
	3	5	215	1785	1·19	8·3
	4	3	165	1456	1·26	10·6
	Average,		165¾	1527½	1·35	11·1

Description.	No. of Class.	No. in Class.	Average Age.	Average Final Weight per head.	Increase per Day.	Increase per 1000 lbs. Live-weight per Week.
			Weeks.	lbs.	lbs.	lbs.
Herefords,	6	10	118½	1615	1·95	14·9
	7	5	165½	1964	1·70	10·9
	8	2	221½	2085	1·34	8·2
	9	2	178½	1731	1·39	10·0
	Average,		171	1848¾	1·60	11·0
Short Horns,	11	6	120	1698	2·02	14·8
	12	10	160	1960	1·75	11·3
	13	5	163	2352	2·06	11·3
	14	10	172	1876	1·56	10·5
	Average,		153¾	1971½	1·85	12·0
Sussex,	16	7	116	1588	1·96	15·2
	17	8	151	1818	1·72	11·9
	18	4	203	2390	1·68	9·1
	19	7	160	1736	1·55	11·1
	Average,		157⅛	1883	1·73	11·8
General average,			162	1808	1·63	11·5
Prize Cattle, Chicago Society, United States.						
1. Steers, 4 years and over, 1st Prize,			268·6	2085	1·10	7·1
2. ,, ,, ,, 2d Prize,			271·7	2440	1·28	7·0
3. ,, 3 yrs. and under, 1st Prize,			182·9	2115	1·65	10·4
4. ,, ,, ,, 2d Prize,			174·3	2060	1·68	10·9
5. ,, 2 ys. and under 3, 1st Prize,			138·4	1705	1·76	13·5
6. ,, ,, ,, 2d Prize,			139·7	1600	1·63	13·4
7. ,, 1 yr. and under 2, 1st Prize,			92·9	1480	2·28	20·0
8. ,, ,, ,, 2d Prize,			95·7	1275	1·90	19·1
Average,			170·5	1845	1·66	12·7
Nivernais-Charolais Cattle—French.						
No. 1,			134·8	1478	1·57	13·6
No. 2,			156·4	1987	1·81	11·9
No. 3,			160·8	1893	1·68	11·6
No. 4,			174·0	2079	1·71	10·8
Average,			156·5	1859	1·69	12·0
General average of all,			163·7	1826	1·65	11·9
Rothamsted adopted average,						10–11

Before discussing the figures given in the Table, it will b well to give some explanation of how they are obtained. Th ages, and the final weight per head, are the actual data recorded The increase per day is obtained by dividing the final weigh by the number of days of age. This is the mode of represen tation adopted in the United States; and the figures given i this column for the Chicago cattle are those actually recorded whilst those for the Smithfield and French cattle are calcu lated as above described. It is obvious that such a mode o reckoning, however valuable it may be in comparing the rate of increase of animals of the same description, oxen, for example but of different breeds, or of different ages, it is quite inappli cable in comparing the rates of increase of animals of differen descriptions, and of different sizes; of oxen, sheep, and pigs, wit one another, for example. Many years ago, when considerin this subject, we felt the necessity of adopting some mode o representation which enabled us to compare the amounts o food consumed, and the amounts of increase produced, not onl among animals of the same, but of different descriptions, an of all sizes. Accordingly, the standards we adopted were:—

The amount of food consumed per 100 lbs. live-weight pe week.

The amount of food required to produce 100 lbs. increase i live-weight.

The increase per 100 lbs. live-weight per week.

But as, on the present occasion, I am dealing with cattl only, I give, as you will see in the last column of the Table the increase per 1000 lbs. live-weight per week. At the foo of this last column is given the average increase per 1000 lbs live-weight per week of all the cases recorded in the Table including the different breeds of the different countries "babies" of two years old and under, and mature animals o four years old and over. This general average of such ver varied individual cases shows 11·9, or nearly 12 lbs. increas per 1000 lbs. live-weight per week, whilst the Rothamste estimate, adopted many years ago, is 10 to 11 lbs. per 1000 lb live-weight per week, as the average rate of increase of oxe during the last few months of feeding on good fattening food To go a little more into detail, compared with this Rothamste estimate of 10 to 11 lbs., the average of the different lots of th

Smithfield prize cattle gives 11·5 lbs., that of all the Chicago cattle 12·7 lbs., and that of the four French cattle 12 lbs.

In making these comparisons it must be borne in mind, however, that whilst in the case of the Smithfield, Chicago, and French cattle, the increase is, for want of other data, calculated upon the average live-weight from birth to final weight, in that of the Rothamsted estimates it is taken upon the average weight of the final fattening period only; and as the rate of gross increase upon a given live-weight within a given time is considerably higher in the earlier than in the later periods of the life of the fattening animal, the figures are, so far, not strictly comparable.

On the other hand, a mature animal contains a larger proportion of saleable carcass, and a less proportion of internal organs, and offal generally, than a young or store one. The mature animal also contains a much higher percentage of dry or solid substance, and, accordingly, a lower percentage of water. These differences are clearly illustrated in the following Table, which gives the proportion of carcass in 100 fasted live-weight, and also the percentages of dry or solid substance, and of water, in 10 animals of different descriptions, and in different conditions as to age and fatness, which were analysed at Rothamsted, now nearly thirty years ago.

TABLE VII.

COMPOSITION OF VARIOUS ANIMALS.

Description and Condition of Animal.	In Fasted Live-weight.		
	Carcass.	Total Dry Substance.	Water.
	Per cent.	Per cent.	Per cent.
Fat Calf, ...	62·0	33·9	63·0
Half-Fat Ox, ...	64·7	40·3	51·5
Fat Ox, ...	66·2	48·6	45·5
Fat Lamb, ...	60·2	43·7	47·7
Store Sheep, ...	53·3	36·7	57·3
Half-Fat Old Sheep, ...	53·6	40·6	50·3
Fat Sheep, ...	57·5	50·7	43·3
Very Fat Sheep, ...	63·1	59·6	35·2
Store Pig, ...	66·4	39·7	55·0
Fat Pig, ...	76·0	54·7	41·4

Thus, you will see that even a fat calf contained a much higher percentage of water, and lower percentage of solid matter, than a half-fat ox; whilst the fat ox contained much more dry or solid matter than the half-fat one. Then, again, among the sheep there is a gradually increasing percentage of dry or solid matter, and decreasing percentage of water, from the store to the half-fat, from the half-fat to the fat, and from the fat to the very fat condition. A similiar result is observed as between the store and the fat pig. From these facts you will see that, although the gross increase is less in proportion to the live-weight as the animal matures, a larger proportion of such gross increase consists of carcass, and of real solid matter, and a less proportion of offal, and of water. In fact, the fattening process may be said to consist in great measure in the displacement of water by fat.

Accepting the figures given in Table VI. as giving a fair idea of the rate of increase of well-bred and well-fed animals, the question arises—at what cost of food has that increase been obtained ? We have no records on this point in regard to any of the animals referred to in the Table. We must, therefore, rely upon other data in arriving at a decision on this part of the subject. Our own estimate, founded on all the data at our command, partly relating to the recorded experience of others, and partly to the results of direct experiments of our own, led us many years ago to conclude as follows :—

" Fattening oxen, liberally fed upon good food, composed of a moderate proportion of cake or corn, some hay or straw chaff, with roots or other succulent food, and well managed, will, on the average, consume 12 to 13 lbs. of the dry substance of such mixed food, per 100 lbs. live-weight, per week; and they should give 1 lb. of increase for 12 to 13 lbs. dry substance so consumed."

In other words, there will be consumed from 120 to 130 lbs. of the dry substance of such mixed food per 1000 lbs. live-weight per week, producing on the average 10 lbs. of increase; and 1200 to 1300 lbs. will, therefore, be required to yield 100 lbs. increase in live-weight. If the mixed food contain no straw-chaff, and only a moderate amount of hay-chaff, the *average* amount of dry substance consumed will be the less, *and the average* proportion of increase the more, or vice versa.

Accordingly, we have assumed that on a liberal mixture of oilcake, clover-chaff, and swedes, as little as 1100 lbs. dry substance may be required to produce 100 lbs. increase, and as much as 11 lbs. increase may be produced per 1000 lbs. live-weight per week.

The articles which you are accustomed to speak of as dry foods, still contain some water. Thus, cakes contain from one-eighth to one-ninth, and corn, hay, and straw, about one-sixth of their weight of water; whilst swedes do not contain more than 10 to 12, or mangolds more than 12 to 13 per cent. of really dry or solid matter; but the monster roots of which we hear so much, sometimes contain only about two-thirds as much dry matter as moderately sized and well-matured roots should do. Of really dry substance, such as my estimates given above require, 1200 to 1300 lbs., say 1250 lbs., would, in round numbers, be supplied in the following amounts of each of the several descriptions of food enumerated, supposing them to be of fair average composition in that respect.

TABLE VIII.

AMOUNT OF EACH FOOD CONTAINING 1250 LBS. DRY MATTER.

Cakes,	12½ cwts.
Corn or Hay,	13 ,,
Swedish Turnips,	5 tons.
Mangolds,	4½ ,,

The question arises—What would be the cost of 1250 lbs. of dry substance, made up of a suitable mixture of these various foods, to yield 100 lbs. increase in live weight, and whether this would be less or more than the 100 lbs. increase would sell for?

Well-bred and moderately fattened oxen should yield 58 to 60 per cent. carcass in fasted live-weight; very fat oxen may yield from 65 to 70 per cent. But of the increase obtained during what may be called the fattening period of moderately fattened oxen, it may be reckoned that about 70 per cent. will be carcass. Supposing you get 8d. per lb. for this, the selling value of your 100 lbs. increase in live-weight will be 46s. 8d. Now, I think if you try to make up 1250 lbs. of dry substance

by a suitable fattening mixture of the foregoing foods, you will find that it will cost you considerably more than 46s. 8d. Even if roots alone were used, which would not be considered good fattening food, the cost would be more if they were reckoned at their selling price, though less if taken at what is called their "consuming value." But with no good fattening mixture of cake or corn, hay-chaff, and roots, could 1250 lbs. of dry matter be obtained for anything approaching the sum I have estimated as the value of the increase it will produce.

It is further to be borne in mind that, weight for weight, store stock is generally dearer than fat stock. You have also to add to the cost of the food various other charges, such as rent of buildings, appliances, attendance, and risk. Taking all these things into account, I think it is evident that there must always be a very considerable proportion of the cost of feeding, although varying greatly according to circumstances, which must be taken to represent the cost of the manure.

In 1876, the Council of the Royal Agricultural Society of England appointed a committee to consider the question of the valuation of unexhausted manures, with reference to the provisions of the Agricultural Holdings Act; and a Table of the estimated value of the manure obtained by the consumption of different articles of food, which I had first published about 16 years previously, and after reconsideration republished more recently, was much discussed and criticised. The general impression arrived at was, I think, that my estimates of manure-value were too high. Accordingly, Dr Gilbert and I selected linseed cake as the best known article of purchased cattle-food, and, after deducting my estimate of the manure-value from the cost of the cake, we endeavoured to calculate whether the remainder of the cost could be recovered in the increased value of the animal. The best linseed cake was then quoted at £12, 10s. per ton, and deducting the manure-value as given in my Table, namely, £4, 12s. 6d., there was left £7, 17s. 6d. to be charged against the animal, and calculation led us to the conclusion that it was extremely doubtful whether this amount could be recovered in its increased value. In fact, linseed cake appeared to us to command what may be called a fancy price. At any rate, it was quite certain that it could not be

profitably used, if not fully as much, or even more, than the amount of my estimate were charged against the manure.

Although in the foregoing illustrations I have confined my attention to oxen, if the same mode of calculation were applied to sheep and to pigs, it would be found in their case also that the cost of their food is more than the value of the increase it produces. Notwithstanding that the contrary view is so frequently assumed, the use of the term "consuming value," as distinguished from selling price, seems to recognise that food stuffs have a value other than as food alone. If restrictions upon the sale of roots, hay, and straw, were abolished, these articles would soon cease to have what may be called a fancy price; and the difference between the so-called "consuming value," and the real selling price, would more nearly represent the value of the manure.

In the former part of my address, I have shown that, beyond a certain limit, the increase of crop does not keep pace with the increase in the amount of manure applied to the land, and that this is especially the case in advancing from high to still higher farming. I have now adduced evidence which must, I think, convince you that the manures of the farm cost money. It seems to me that an obvious deduction from these two facts is, that to apply manure in such quantity as to obtain a diminished produce for a given amount of it can only be profitable when the price of the produce rises, and not when it falls. So far, however, as increased production is to be attained by the exercise of freedom, intelligence, and economy, in management, so as to get the maximum amount and value of produce from the manure that is applied to the land, and the maximum amount and value of meat and manure for the outlay in store-stock and in food, increased production is a necessity of the times, and would prove the best remedy for lower prices of farm produce.

I regret to find that the opinions I hold, and have ventured to express to you, are not in accordance with those of many who write upon the condition of the farming interest at the present time. Nor do they quite accord with the advice given to you in this room, by Lord Polwarth, only in February last. In a letter which his lordship subsequently published, in

further explanation of his views, he said that, for increased production, "greater liberty in cultivation is desirable;" and again, that, "there must be increased capital, scope for enterprise, and security of tenure." In this I entirely agree, excepting that I would venture to say that such changes are not only "desirable" but essential.

To attempt to meet falling prices by increased production upon the old lines, that is, by simply increasing the amount of manure brought upon the land, and at the same time maintaining the old rules and restrictions as to cropping and sales, would, in my opinion, be entirely futile. If all restrictions were abolished, excepting such as would secure that the tenant should give up his farm in as good a state as he entered upon it, the position of things would be entirely changed, and some of my remarks would then require modification accordingly.

Recent discussions clearly show that landowners fully recognise the gravity of the present state of affairs, and that they are desirous of assisting the tenant by the relaxation of existing covenants, and in other ways. In addressing tenant-farmers, I would venture to ask—whether, on their side, this is not a favourable opportunity for taking stock of the modes in which they conduct their business, with the view of bringing their operations more into accord with the rules which regulate other commercial undertakings?

In illustration of my meaning, I will call attention to the way in which the business connected with the stock of the farm is generally conducted. Farmers are justly proud of their fine animals, and consider them to be the back-bone of British agriculture. But is it not a fact that every transaction in this immense branch of industry is carried on almost exclusively by guess-work? Neither in purchasing store-stock, nor in selling fat stock, are the scales brought into requisition. Again, in the feeding operations, neither the amount of increase produced, the amount and the cost of the food required to produce it, nor the comparative value of different foods in regard to their feeding and manure productiveness, are taken into calculation.

Of late, store-stock have been very dear, and I have little doubt that, if tested by the scales, it would be found that *oxen and sheep* have been bought at prices which would

represent 6d. per lb. Now, 6d. per lb. is £56 per ton. To purchase 10 tons of store-stock would not be a very large purchase to make. Now, I should like to ask the best judges of stock in this room to pick out from a herd of oxen, or a flock of sheep, as many as they thought would make up 10 tons in weight; or to see, if two or three went to work independently, how nearly their estimates would agree! If your coal-merchant, or your manure-dealer, proposed to sell you those commodities by the heap, you would not hear of such a thing, and you would insist upon purchasing by weight. But, weight for weight, these articles bear no comparison in value with that of animals. If, then, with articles of comparatively little value you will not buy by the lump, regardless of exact weight, why should you do so with anything so costly as your store-stock? I admit that I am myself compelled to adopt the custom of the trade; but I nevertheless thoroughly resent it, and feel that I never know whether my purchase has been a good or a bad one, until I have brought the animals to the scales, and calculated the price per pound of live-weight. The eye is the proper judge of quality, and the price per pound, or per cwt., should be settled accordingly; and, this done, the total value should be settled by the scales.

The same plan of guessing is adopted in the sale of the fat stock. Here the butcher is sure to have the best of the bargain; for every day his guesses are checked by reference to the scales, whilst the farmers are not, and what chance has the feeder, or his salesman, against such an advantage as this?

If the farmers of the country at large were to agree to declare that they would only buy and sell stock by weight, they would doubtless have ample power to enforce their decision.

The same indifference to weights is manifested throughout, from the birth of the animal until it reaches the butcher. There is the clearest evidence of this in the discussions of the subject amongst farmers themselves, whether at home, at the market table, or at the clubs. If the custom of buying and selling stock by weight were once established, and it is so already to a great extent in America, the advantages to the farmer would be very great in various ways. He would not only be able to test the money result of his actual purchases

and sales, but he would gain much experience, which would sharpen his judgment in the matter in the future. A greater advantage still would be, that he would be led to test his practice at every intermediate stage between the breeding or the buying and the selling. He would ascertain what were the best mixtures of food to use, according to the seasons and to the markets. He would determine—whether his animals were giving a proper rate of increase; how much of different foods they required to produce it; and he would carefully consider also the manure-value of the different foods. He would, in short, take the only means of insuring economy in his meat and manure manufacture.

I was asked by your Secretary to address you this evening on the most economical method of producing meat. But I felt that, as the only way in which I could properly treat the subject would be by reference to weights, both of the food and of the animals, it would be, to many, neither interesting nor instructive; it would, in fact, be like speaking in an unknown tongue.

I will endeavour to illustrate my meaning by reference to a question which is much discussed at the present time—namely, the relative economy of producing *young* or *old* beef.

If you look at Table VI., to which I have already called attention, you will find that in the top line of each of the four divisions, relating, respectively, to the four English breeds, you have an example of early maturity; and the increase per day, and the calculated increase per 1000 lbs. live-weight per week, show, by comparison with the older animals, a more favourable rate of increase. To produce the same weight in two years as would otherwise be only attained in three years or more, is, of course, in many points of view, a great gain. As animals consume and expend a given amount of food daily, in proportion to their weight, merely in the maintenance of their existence, it is obvious that there is, so far, a considerable saving of food if the same weight is attained in one-half or two-thirds the time. Other expenses will also be more or less reduced the shorter the time required to produce a given weight. It is true that, so long as an animal only feeds in a pasture in the summer, and only receives straw and roots in

the winter, it lives at comparatively little cost, even if it make but slow progress, until the final period of fattening begins. Again, as the animal matures, it consumes less food for a given live-weight within a given time, a given weight of food gives rather less gross increase, but a given weight of gross increase represents more carcass, more solid matter, and less water. On the other hand, to obtain the more rapid increase, much more costly food must be given throughout the life of the animal.

It is obvious that the two systems cannot be fairly compared, without taking into the calculation accurate data—as to the cost of attendance, the quality, quantity, and cost of the food consumed, the rate and value of the increase, and the value of the manure in the two cases. Yet in none of the discussions of the subject of which I have seen the records has there been any attempt to bring figures relating to these various points to bear upon the question.

A few weeks ago there was an article in the *North British Agriculturist* headed "Young *v.* Old Beef." The Editor justly speaks of the excellence of the article, which he says was written by a well-known shorthorn breeder, who has oftener than once tasted the sweets of first honours at the Smithfield and other National Fat Shows. The writer gives the increase of weight of five cattle, of different ages, from March 1 to November 1. He says, that the animals were fed on the best he could procure for them, were all healthy during the experiment, and all figured as first prize takers at Christmas Shows. But, he adds, the food was not weighed; and further on he says, "this instance I have selected from many in my note books of live-weights of animals, and increase at different times; and the proportionate increase of weight of different aged animals is fairly stated in the above examples."

I gather from these statements that it is assumed by the writer that the rates of increase quoted are what may be expected in the case of first-class shorthorns of the ages given, and fed upon the best food that can be procured for them. They were as follows; and I have added a column showing the rate of increase per head per week, obtained by dividing the total increase by 35, the number of weeks from March 1 to *November 1*:—

	Increase in Live-weight.	
	From March 1 to November 1.	Per head per week.
	Cwts. qrs. lbs.	lbs.
1 Four-year-old, ...	1 2 0	4¾
1 Three-year-old, ...	2 0 0	6⅛
3 Two-year-olds (average per head), .	4 0 24	13½

The actual weights of the animals are not given. But it may be assumed that the four-year-old ox would weigh nearer 2000 lbs. than 1000 lbs.; so that the rate of increase would probably not be more than 2½ or 3 lbs. per 1000 lbs. live-weight per week, instead of 10 to 11 lbs. according to our estimate. Nor would either of the younger animals show a sufficient rate of increase; though the evidence is certainly very much in favour of the younger animals. The 4¾ lbs. increase per head per week of the four-year-old would be worth about two shillings; and I leave you to judge what relation that sum would bear to the cost of feeding a four-year-old shorthorn on the best of everything! These figures afford some idea of the cost of obtaining a prize, but they are of no value as examples of profitable feeding.

It must be understood that in making these remarks I do not wish to find any fault with the writer, who is obviously a man of much intelligence and experience. But I wish to enter a protest against the system of disregarding attention to the weights of animals, to their rates of increase, and to the quality, quantity, and cost, of the food they consume to produce it, which alone could render it possible that such results could be quoted as examples of successful feeding.

It is a somewhat humiliating admission to make, though so far it has proved to be too true, that the virgin soils and plains of the United States and Canada can produce, and send to this country, corn and meat cheaper than they can be produced on our own soils at home, with all our boasted skill and science. The opinion expressed by some, that we shall again become *exporters of* corn, is altogether chimerical. But we have at *any rate the* cost of transit in favour of home production.

This, though a less considerable protection in the case of grain, must always be a material item in the case of live animals, and of meat; and the rearing and feeding of stock must always form an important branch of our farming.

It is such a generally accepted opinion that the agriculture of Great Britain is superior to that of any other country, that you will perhaps be disposed to resent the allegation that there is very much in your practice which requires improvement. During the last thirty or forty years, our knowledge of the productive effects of different manures, of the food requirements of different animals, of the increase they should yield, and of the value of the manure they produce, has made great progress. But comparatively few British farmers pay any attention to such subjects, or care to avail themselves of the information at their disposal. It is true that much of the existing data is not yet available in a form which would be easily intelligible to farmers generally, but this is because there is little demand for such knowledge; and a comparison of the current agricultural literature of this country with that of America, and of some parts of the European continent, would show that the demand is greater in those countries. So long, indeed, as the old routine yielded fair profits, what need was there of any change? But the present crisis, though I fear it may bring loss and suffering to many, will not be without some advantages, if it should lead to the conduct of agricultural operations on a basis more in accordance with both commercial and scientific principles.

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"Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than twenty years in succession on the same land."

By J. B. Lawes, LL.D., F.R.S., F.C.S., and J. H. Gilbert, Ph.D., F.R.S., F.C.S., F.L.S. Received June 16, 1879.

(Abstract.)

In the experiments at Rothamsted with different manures, wheat has now been grown for thirty-six years in succession on the same land, barley for twenty-eight years, and oats for nine years. Somewhat in like manner, but with some breaks, beans have been grown over a period of more than thirty years, clover for many years, and "root-crops" (turnips, sugarbeet, or mangel-wurzel) also for more than thirty years. Each of these individual crops has exhibited certain distinctive characters under this unusual treatment. But, withal, those of the same natural family, wheat, barley, and oats, for example, have shown certain characters in common, those of the Leguminous family characters widely different, whilst the so-called root-crops, belonging to the Cruciferous and Chenopodiaceous families, have exhibited characteristics differing from those of either the Gramineæ or the Leguminosæ.

Compared with the conditions of growth of any one of these individual crops grown separately, those of the mixed herbage of grass land are obviously extremely complicated. Thus, it comprises, besides numerous genera and species of the gramineous and leguminous families, representatives also of many other natural orders, and of some of great prominence and importance as regards their prevalence and distribution in vegetation generally. And if, under the influence of characteristically different manuring agents, as has been the case, there have been observed notable differences in the degree of luxuriance of growth, and in the character of development, even between closely allied plants when each is grown separately, and much greater differences between the representatives of different families when so separately grown, might we not expect very remarkable variations of result, when different manures are applied to an already established mixed herbage of perhaps some fifty species growing together, representing nearly as many genera and more than twenty natural orders?

Such, far beyond what could have been anticipated, has been the case in the experiments described. So complicated, indeed, have been the manifestations of the "struggle" that has been set up, that, even after more than twenty years of laborious experiment, both in the field and in the laboratory, and following up both the botany and the chemistry of the subject, we can hardly claim to have yet done

much more than reach the threshold of a very comprehensive inquiry. Still, we hope to establish some points of general interest; and possibly to indicate promising paths of future research.

From the title of our paper, it will at once be concluded that the experiments were originally undertaken and arranged from an agricultural point of view. But, as experimenting on the feeding of animals soon led us into lines of inquiry of even more interest to the chemist, the animal physiologist, and the dietetician, than to the agriculturist, so the investigation of the effects of different manures on the mixed herbage of grass land has led us far beyond the limits of a purely agricultural problem, and has afforded results of more interest to the botanist, the vegetable physiologist, and the chemist, than to the farmer. Indeed, agriculture, the most primitive, and commonly esteemed the rudest of the arts, requires for the elucidation of the principles involved in its various practices, a very wide range of scientific inquiry; and the investigation of them may, in its turn, contribute facts of interest to the student of various and very distinct branches of natural knowledge.

It will be readily understood that, as a necessary foundation for the discussion of the botany and the chemistry of the subject, it will be essential first to put on record, and call attention to, what may be distinguished as the agricultural data. It is proposed, then, to arrange and consider the results obtained under the following heads:—

Part I. .... The Agricultural Results.
Part II. .... The Botanical Results.
Part III. .... The Chemical Results.

The general scope, objects, and results of the whole inquiry may be briefly indicated as follows:—

About seven acres in the park at Rothamsted have been set apart for the experiments, and divided into plots. Two of these have been left without manure from the commencement; two have received ordinary farm-yard manure, whilst the remainder have each received a different description of artifical or chemical manure, the same being, except in special cases, applied year after year on the same plot.

Referring first to the *Agricultural Results*, it may be premised that, *without manure*, the produce of hay has varied from year to year, according to season, from about 8 cwt. to nearly 39 cwt. per acre, and the average yield has been about 23 cwt. per acre per annum. On the other hand, the plot the most heavily artificially manured, and yielding the highest amount of produce, has given an average of about 64 cwts. of hay per acre per annum, with a variation from year to year from under 40 cwts. to nearly 80 cwts. Intermediate between the extremes here quoted, very great variation in the amount of produce has been exhibited on the other differently manured plots.

With these great differences in the amounts of produce the botanical character of the herbage has varied most strikingly. Thus, starting with perhaps fifty species on the unmanured land, any kind of manure, that is, anything that increases the growth of any species, induces a struggle, greater or less in degree, causing a greater or less diminution, or a disappearance, of some other species; until, on some plots, and in some seasons, less than 20 species have been observable, and on some, after a number of years, no more than this are ever traceable.

Even in the first years of the experiments it was noticed that those manures which are the most effective with wheat, barley, or oats, grown on arable land, that is, with gramineous species grown separately, were also the most effective in bringing forward the grasses proper, in the mixed herbage; and, again, those manures which were the most beneficial to beans or clover, the most developed the leguminous species of the mixed herbage, and *vice versâ.* It was further observed that there was great variation in the predominance of individual species among the grasses, and also among the representatives of other orders. And even in the second year the differences in the flora, so to speak, were so marked, that a first attempt at a botanical analysis of carefully taken samples of the produce of some of the plots was then made; in the third year more detailed separations were made; and, taking advantage of the experience thus gained, pretty complete botanical analyses have since been conducted four times, at intervals of five years, during the course of the now twenty-four years of the experiments; and on several other occasions partial separations have been undertaken. The character and tendency of the results so obtained may be very briefly indicated as follows:—

In the produce grown continuously without manure the average number of species found has been 49. Of these, 17 are grasses, 4 belong to the order Leguminosæ, and 28 to other orders. The percentage by weight of the grasses has averaged about 68, that of the Leguminosæ about 9, and that of species of other orders 23.

In the produce of the plot already referred to as the most heavily manured, and yielding the heaviest crops, the average number of species found has been only 19, of which 12—13 are grasses, one only (or none) leguminous, and 5—6 only represent other orders; whilst the average proportions by weight have been—of grasses about 95 per cent., of Leguminosæ less than 0·01 per cent., and of species representing other orders less than 5 per cent.

On the other hand, a plot receiving annually manures such as are of little avail for gramineous crops grown separately in rotation, but which favour beans or clover so grown, has given on the average 43 species. Of these 17 in number are grasses, 4 Leguminosæ, and 22 belong to other orders; but by weight the percentage of grasses has

averaged only 65—70, that of the Leguminosæ nearly 20, and that
species belonging to other orders less than 15.

With such very great variations not only in the amount, but in t
botanical character of the produce of a crop under any circumstanc
so complex, it might be anticipated that there would be very gre
differences in its chemical composition, partly due directly to t
supply of constituents by manure, partly to variation in the descri
tion of plants encouraged, and partly to the character and degree
development and ripeness of the varying components of the mix
herbage, according to the season and to the manure employed.

With a view to the elucidation of this part of the subject, the d
matter and the ash have been determined in the produce of every pl
in every season, the nitrogen in that of all the plots for many of t
seasons, and in some cases the amount of it existing as albuminoi
has been determined. In selected cases also comparative determi
tions of "crude woody-fibre" and of crude fatty matter have be
made. About 120 complete ash analyses have been executed. A
lastly, samples of the soil of every plot, in some cases at differe
periods, and in most cases representing the first, second, third, four
fifth, and sixth depths of 9 inches, or in all to a total depth of
inches, have been collected, and these have been chemically examin
in various ways.

It is found that there is a considerable difference in the percenta
of dry substance in the produce, and very considerable difference
the percentage of mineral matter (or ash) in that dry substan
There is still greater difference in the percentage of nitrogen in t
dry matter, and again, a greater difference still in the percentage
individual constituents of the ash. When indeed it is remembered t
a plot may have from 20 to 50 different species growing upon it, ea
with its own peculiar habit of growth, and consequent varying ra
and power of food-collection, it will not appear surprising t
different species are developed according to the manure employ
and, this being so, that the character and amount of the constitue
taken up from the soil by such a *mixed herbage* should be found m
more directly dependent on the supplies of them by manure than is
case with a crop of a single species growing separately.

In further illustration it may be mentioned that, not only does
percentage of nitrogen in the produce of the different plots vary c
siderably, but the average annual amount of it assimilated over a gi
area is more than three times as much in some cases as in oth
Again, the percentage of potass in the dry substance is more t
double as much in some cases as in others; whilst the difference in
average annual amount of it taken up over a given area is more t
five times as much on some plots as on others, dependent on the supp
of it by manure, and the consequent description of plants, and amo

and character of growth induced. The percentage and acreage amounts of phosphoric acid also vary very strikingly; and so again it is with other mineral constituents, but in a less marked degree.

It will be seen that in the history of so many of what may be called natural rotations, we can hardy fail to learn much that is of interest, not only in reference to the growth of the mixed herbage of permanent grass land, but also something of the relative positions of the different plants that are grown separately, in alternation with one another, in the artificial rotations adopted on arable land.

The botanical results are, moreover, of much independent interest, both by the facts which they already contribute, and by the incentive and direction they may give to future research.

Lastly, the chemistry of the subject will be found to offer many points of interest, in regard to the variation in the percentage composition of the produce, according to the manure applied; to the description of plants developed, and to the character of their development; to the availableness of the constituents artificially supplied; and to the amount and limit of the natural resources of the soil, both actually and compared with the results obtained when individual species are grown in arable culture.

It will be readily understood that the record, and the discussion, of the agricultural, the botanical, and the chemical history of about 20 plots, in 20 different seasons, must involve much detail; and although it is obvious that facts special to any one of the three main divisions of the subject may require for their elucidation reference to those of one or both of the others, it is still believed that it will conduce to clearness, and reduce unavoidable repetition, to maintain the divisions proposed as far as possible.

On the present occasion, Part I only, entitled—"The Agricultural Results," is presented. In Part II, "The Botanical Results," which will next follow, Dr. M. T. Masters, F.R.S., is joint author.

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From the REPORT *of the* BRITISH ASSOCIATION *for the* ADVANCEMENT *of* SCIENCE *for* 1879.]

On some points in connection with Agricultural Chemistry. *By* DR. J. H. GILBERT, *F.R.S.*

·. Gilbert stated that in the experiments of Mr. Lawes and himself, conducted › farm of Mr. Lawes, at Rothamsted, Herts, wheat had now been grown for -six years in succession on the same land; barley for twenty-eight years in sion, oats for nine years, root crops for more than thirty years, beans for more hirty years, and they had experimented on the mixed herbage of grass land 'enty-four years. They found minor distinctions in the manurial requirements ferent plants of the same natural family, but very great distinctions in the ements of plants of different natural families. The gramineous crops are very their percentage of nitrogen, and yield but a small quantity of it per acre. trogenous manures are very effective when applied to such crops. Legumi- rops, on the other hand, are very high in their percentage of nitrogen, and large amount of it per acre. Yet nitrogenous manures are of little avail to lants, and potass manure is especially effective. The difference in the manure ments of plants of other natural families was also pointed out. Much more cated, however, was the problem when experiments were made upon the herbage of grass land, where they might have fifty or more species growing ciation, representing perhaps twenty natural families. It was at once found e manures which most favoured gramineous crops separately grown on arable rought forward the gramineous plants of the mixed herbage. Those, on the hand, which favoured the leguminosæ, grown separately, on arable land, t forward the leguminosæ in the mixed herbage. Somewhat similar results d with the plants of other natural families. Hence, the twenty different plots e experiments soon showed as many distinct floras. Tables were exhibited ting the variation in the number of species, their percentage by weight, and ounts which the different natural families yielded per acre. With the great ce, not only in the flora, but also in the character of development of the there was the greatest possible difference in the chemical composition. The tter of the mixed herbage contained in some cases 1½ time as much nitrogen thers. The percentage of potass in the produce varied as one to two, and ount of potass yielded per acre as one to five in the different experiments; ere were considerable differences among the other constituents. The produce respective natural families possessed its own normal composition within certain Yet this was varied immensely according to the conditions supplied, and aracter of the produce grown. Thus, the ash of the gramineous produce l a variation in the percentage of potass of from about 24 to about 40; the the leguminous produce from 12 to 33; and that of the miscellaneous pro- rom 17 to 37. One point of especial interest was the difference in the t of nitrogen yielded by the plants of the different natural families. It was d by some that some plants assimilated the free nitrogen of the atmo- ; but the authors considered that the balance of the direct experimental ce on the point was decidedly against such a supposition; and so far as their g evidence went they considered it much more probable that the different only took up combined nitrogen, and chiefly from the soil. They showed rence to their *experiments that* in the growth of wheat or barley for many *n succession on the same land* without nitrogenous manure the annual yield *gen in the crop gradually* diminished. With this they found a diminution

in the percentage of nitrogen in the soil. In the case of the root crops, diminution in the annual yield of nitrogen was even greater than in the c cereals, the diminution in the percentage of the nitrogen in the soil was als In the case of beans there was also a diminution in the yield of nitrog crop, but still much more was yielded over the later period than in eit or barley. In this case there was not found a marked reduction of ni the surface soil. In the case of the mixed herbage experiments very m nitrogen was yielded by the application of potass manure; and here the great reduction in the percentage of nitrogen in the soil. In the case grown for many years in garden soil, the percentage of nitrogen in th also very largely reduced. Part of this reduction might be due to oth but the indication was that the leguminosæ had derived their nitrogen soil. Admitting that the sources of the whole of the nitrogen of vegeta not conclusively made out, they nevertheless considered that the existing was against the idea of the assimilation of free nitrogen by plants, and in the opinion that the nitrogen was mainly, if not entirely, derived thi medium of the soil.

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OUR CLIMATE

AND

OUR WHEAT-CROPS.

BY J. B. LAWES, LL.D., F.R.S., F.C.S.,

AND

J. H. GILBERT, PH.D., F.R.S., F.C.S.

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OUR CLIMATE AND OUR WHEAT-CROPS.

Introduction.

Since the publication of our Paper, "On the Home Produce Imports, and Consumption of Wheat," in this 'Journal' in 1868 (vol. vi. s.s., part 2), more than eleven years have passed away, —years during which the agricultural interests of these islands have experienced a transition from a state of great prosperity to one of great depression,—years during which the worst features of our climate have been exhibited in unusual frequency, and which have terminated with a season, not only by far the worst for the wheat-crop since the commencement of our experiments on the continuous growth of the crop in 1843–4, but probably the very worst that has occurred since observers have furnished us with records of temperature and rainfall, and with other weather statistics.

It has been remarked that, so far as climate is concerned, the British Isles are outside the zone favourable to the growth of wheat, and that its successful cultivation is due to the skill of the farmer in contending against adverse meteorological conditions. It is true that the area under the crop is rapidly diminishing, and that its continued growth appears to gravitate to those districts where the climate, or the soil, or the combination of the two, is the most favourable. But the great decline in area cannot be attributed to any general change for the worse in the characters of the climate. Indeed, Mr. Glaisher has recently called attention to the fact that, dividing the last 108 years into six periods of eighteen years each, there is even a slight progressive increase of mean temperature from the first to the last of those six periods. It is to the greatly increased production of wheat in other countries, at a lower cost than in our own, and to low rates of transport, by which it is brought into our markets in quantity and at a price much reducing the value of the home-produce, that the reduced area under the crop is chiefly to be attributed.

As only about 5 per cent. of the total wheat-crop is derive from the soil itself, the remainder coming, directly or indirectly from the atmosphere, and as the amount of matter accumulate from either source depends mainly on the quantity, and th relations to one another, of heat and moisture, we cannot b surprised that the character of the seasons exercises such a pre ponderating influence over the growth of our crops. As yet however, the connection between meteorological phenomena an the progress of vegetation is not so clearly comprehended as t enable us to estimate with any accuracy the yield of a crop b studying the statistics of the weather during the period of it growth. Experience does, indeed, teach us that we may expec better crops under certain conditions of the weather than unde others. But it is only by a careful comparison of the character of the seasons on the one hand, and of the quantity and qualit of the produce on the other, for many years, that we can hope t acquire sufficient knowledge to enable us to assign to the variou agencies, the sum of which constitutes the climate of the yea their respective values in the production of the crop. As we hav said before (this 'Journal,' vol. ix., part 1, p. 96):—"Thus, i is obvious that different seasons will differ almost infinitely a each succeeding period of their advance, and that, with eac variation, the character of development of the plant will also var tending to luxuriance, or to maturation, that is, to quantity, or t quality, as the case may be. Hence, only a very detailed considera tion of climatic statistics, taken together with careful periodi observations in the field, can afford a really clear perception o the connection between the ever-fluctuating characters of seaso and the equally fluctuating characters of growth and produc It is, in fact, the distribution of the various elements making u the season, their mutual adaptations, and their adaptation to th stage of growth of the plant, which throughout influence th tendency to produce quantity or quality. It not unfrequentl happens, too, that some passing conditions, not indicated by summary of the meteorological registry, may affect the crop ver strikingly; and thus the cause will be overlooked, unless carefu observations be also made, and the stage of progress, and tenden cies of growth, of the crop itself at the time, be likewise taken int account."

Still, such records as we do possess, of the conditions as to tem perature and moisture of different seasons, are sufficient to accoun in great measure for the great variation in the quantity and th quality of our crops. The actual amount of rainfall must, how ever, be carefully considered both in connection with its distri *bution* and with the temperature of the period. For example, i *is obvious that* a given amount of rain, equally distribute *through the spring* and summer in each of two seasons, wi

have a very widely different effect on vegetation in the two cases, if the one season should be at the same time a hot and the other a cold one. Or, if the temperature of the two seasons be the same, but the rainfall very different, either in amount, or distribution, or both, so also will the effect on vegetation be very different. It is generally supposed that the temperature of our summers is not, on the average, sufficiently high for the production of abundant and well-ripened crops of wheat; and that it is in the hottest seasons that the produce is the most abundant. This may be the case so far as a certain class of soils is concerned. But a good deal of wheat is grown upon light land, on which the crop suffers considerably in a season of drought or unusual heat. It would appear that the defect of our climate for the production of wheat is more connected with an excess of moisture than with a deficiency of heat, during the periods of active growth and maturing. It is, in fact, when a cold season, or one of only moderate temperature, is accompanied by an excess of rain, that we find the yield of our wheat-crops is the most defective.

I. Seasons of High and of Low Productiveness.

Before entering upon any detailed consideration of the peculiarities of the season and of the experimental wheat-crops at Rothamsted, in 1879, we will endeavour to illustrate, in broad outline, the general characters of season under which some of the best and some of the worst wheat-crops of which we have the record, or the experience, have been grown in this country. For this purpose we will disregard any special characters of the seasons in question at Rothamsted, and draw our illustrations entirely from independent data; namely, the records of the observations of temperature and rainfall made at the Royal Observatory at Greenwich; and we adopt, for the most part, those published by Mr. Glaisher. It is obvious that even such data are more or less local in their application; still, they do indicate the general character of the different seasons, and their distinction from one another.

In Tables I. II. and III., which follow, are given the particulars of the temperature and rainfall of fourteen seasons during the present century, each of which was more or less remarkable so far as the growth of the wheat-crop is concerned. These are 1816, 1832, 1833, 1834, 1835, 1853, 1854, 1857, 1860, 1863, 1864, 1868, 1870, and 1879. The first and the last of them, 1816 and 1879, have the character of yielding the two worst wheat-crops within the period included by those dates, if not indeed within *the century*. Some of the others were, also, *seasons of great deficiency*; but others, though, as will presently

TABLE I.—TEMPERATURE of SELECTED SEASONS, of HIGH and of LOW PRODUCE of WHEAT.

MONTHS.	Season 1815–16.	Season 1831–2.	Season 1832–3.	Season 1833–4.	Season 1834–5.	Season 1852–3.	Season 1853–4.	Season 1856–7.	Season 1859–60.	Season 1862–3.	Season 1863–4.	Season 1867–8.	Season 1869–70.	Season 1878–9.	Average 108 Years, 1771–1878.
	MONTHLY MEAN TEMPERATURE AT GREENWICH.*														
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
October ..	50·1	55·0	51·2	48·3	50·5	47·9	50·9	51·7	50·9	51·8	51·6	48·7	48·9	51·5	49·6
November ..	38·0	44·3	43·7	43·5	44·1	48·9	42·1	40·7	42·1	39·8	45·7	41·4	43·0	39·7	40·8
December ..	36·6	42·0	42·4	44·6	41·0	47·6	34·0	40·2	36 8	43·6	43·2	37·5	37·9	33·7	39·2
January ..	36·3	37·3	34·5	44·4	33·0	42·4	39·0	36·6	39·7	41·8	36·5	37·2	38·8	31·9	36·6
February ..	34·5	36·9	42·4	40·2	41·2	33·3	39·5	39·2	35·7	42·1	36·0	43·0	36·2	38·2	38·7
March ..	39·4	40·5	37·6	44·0	41·0	38·5	43·8	41·8	41·1	43·9	41·8	44·0	39·6	41·2	41·1
April	43·6	47·2	45·2	45·0	46·4	45·2	48·4	45·7	42·9	49·1	48·2	48·1	48·9	48·2	46·1
May	49·3	51·5	59·4	56·9	52·9	52·0	50·9	54·0	53·8	52·0	53·8	57·3	53·4	48·4	52·5
June	55·1	59·2	59·8	61·1	60·0	58·2	55·7	61·8	54·8	58·1	57·4	62·0	60·9	56·9	58·2
July	57·0	61·2	61·1	64·1	64·4	60·3	60·8	64·5	57·9	60·8	61·8	67·5	65·4	58·1	61·6
August ..	56·8	61·0	57·5	62·3	63·3	60·0	60·9	65·8	57·7	61·9	59·6	63·6	61·1	59·9	60·9
September	54·1	56·6	53·5	58·8	57·1	55·8	58·1	59·7	53·4	53·7	56·9	60·5	55·7	56·8	56·5
Average	45·9	49·4	49 0	51·1	50·0	49·1	48·6	50·1	47·2	49·8	49·8	50·9	49·1	46·6	48·6

* All from Mr Glaisher's table, Phil. Trans. Part II. 1850, and from a manuscript table kindly supplied by him for the later ...

TABLE II.—RAINFALL of SELECTED SEASONS, of HIGH and of LOW PRODUCE of WHEAT.

MONTHLY RAINFALL AT GREENWICH.*

MONTHS.	Season 1815–16.	Season 1831–2.	Season 1832–3.	Season 1833–4.	Season 1834–5.	Season 1852–3.	Season 1853–4.	Season 1856–7.	Season 1859–60.	Season 1862–3.	Season 1863–4.	Season 1867–8.	Season 1869–70.	Season 1878–9.	Average 63 Years, 1815–1877.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
October ..	2·63	5·50	2·53	1·32	0·44	3·75	4·23	1·91	3·60	4·07	1·82	2·14	1·77	1·66	2·8
November ..	1·51	2·10	1·65	2·31	1·32	6·00	1·95	1·25	2·90	1·00	1·59	0·42	2·38	3·45	2·4
December ..	2·26	2·10	1·10	4·84	1·10	2·20	0·80	1·83	2·17	1·59	1·08	1·97	2·77	1·16	2·1
January ..	2·09	1·21	1·10	3·08	0·66	2·11	1·40	2·60	1·81	2·71	0·88	4·19	1·49	2·59	2·0
February ..	1·62	1·60	3·63	0·44	2·64	1·48	1·21	0·20	1·10	0·50	0·76	1·28	0·54	3·82	1·5
March ..	1·88	1·43	0·99	0·66	2·53	1·50	0·32	0·83	1·86	0·70	2·53	1·07	2·05	0·60	1·6
April	2·13	0·44	1·21	0·55	1·10	3·21	0·59	1·40	1·00	0·45	0·82	2·08	0·28	2·60	1·7
May	2·15	1·54	0·22	0·99	3·08	1·50	3·51	0·33	3·90	1·25	2·00	1·67	0·47	3·36	2·0
June	2·41	3·30	2·09	1·54	2 42	2·75	0·91	2·70	5·80	3·91	0·92	0·47	0·39	4·29	1·9
July	4·30	0·66	1·65	5·28	0·33	5·48	1·75	1·10	2·80	0·88	0·27	1·06	2·01	3·72	2·6
August ..	2·53	3·41	1·76	3·30	1·10	2·75	2·61	2·50	3·68	1·82	1·31	2·61	2·02	5·19	2·4
September	2·05	0·44	1·87	0·88	4·18	2·23	0·98	3·40	3·10	2·95	2·76	1·52	1·63	2·87	2·4
Total ..	27·56	23·73	19·80	25·19	20·90	34·96	20·26	20·05	33·72	21·83	16·74	20·48	17·80	35·31	25·4

* For 1815–16 we adopt data kindly supplied by Mr. George Dines. For 1831–2, 1832–3, 1833–4, and 1834–5, we take the figures given by Mr. James Simpson, Jun. ('Metropolitan Drainage Reports,' 1857, Appendix III.), which also correspond with those adopted by Mr. Dines and others. For 1852–3, 1853–4, 1856–7, 1859–60, and 1862–3, results kindly provided by Mr. William Ellis; and for 1863–4, 1867–8, and 1869–70, Mr. Glaisher's records ('Proceedings and Quarterly Journals of the Meteorological Society') are adopted. For 1878–9, the Registrar-General's weekly returns are taken.

TABLE III.—RAINFALL of SELECTED SEASONS, of HIGH and of LOW PRODUCE of WHEAT.

MONTHS.	Season 1815–16.	Season 1831–2.	Season 1832–3.	Season 1833–4.	Season 1834–5.	Season 1852–3.	Season 1853–4.	Season 1856–7.	Season 1859–60.	Season 1862–3.	Season 1863–4.	Season 1867–8.	Season 1869–70.	Season 1878–9.	Average 55 Years, 1815–1869.
NUMBER OF DAYS ON WHICH 0·01 INCH OR MORE FELL, AT GREENWICH.*															
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
October ..	14	19	16	13	9	15	27	10	23	16	17	21	11	13	14
November ..	11	15	15	10	10	22	11	10	20	8	11	5	11	15	13
December ..	20	19	16	27	7	19	12	13	20	16	8	12	13	16	12
January ..	16	10	9	26	8	20	15	19	22	16	11	21	15	12	12
February ..	9	7	21	11	16	13	8	3	17	9	12	11	12	21	11
March ..	13	14	12	7	19	14	6	10	22	10	15	16	11	14	12
April	14	7	21	7	10	16	7	18	15	9	4	10	6	16	11
May	15	13	8	7	14	12	16	5	16	10	10	6	5	15	11
June	13	13	14	9	7	17	12	9	24	14	10	5	4	20	11
July	24	5	9	13	6	17	15	9	11	8	8	6	10	19	11
August ..	18	17	7	10	4	10	12	11	25	13	5	12	10	20	11
September ..	14	6	14	9	19	15	9	13	17	14	16	9	8	14	12
Total ..	181	145	157	149	129	190	150	130	230	138	122	134	116	195	141

* According to Mr. Glaisher's records ('Proceedings and Quarterly Journals of the Meteorological Society'), and for 1878–9, the

be seen, they were in some points essentially different from one another, were nevertheless characterised by yielding very abundant crops, of very good quality; some of them, it is supposed, the most abundant within the period under review. By the side of the particulars of temperature and rainfall of each of those fourteen seasons there are given the mean temperature of 108 years, the average rainfall of 63 years, and the average number of days of rain of 55 years. It will be observed that each "season" is here reckoned to include the last three months of the year preceding that of the crop, as the characters of the autumn and early winter may materially affect the getting in of the seed and the early progress of the plant.

We will first call attention to the characters of four consecutive seasons of reputed very high productiveness, which occurred before the commencement of the Rothamsted experiments, and of which we have only such knowledge as is on record respecting them. These are 1832, 1833, 1834, and 1835. Among this series 1834 was by far the most abundant; and it is generally referred to as one of the most productive of the century. So abundant were these four wheat-crops, that the average price, even under protection, went down from 54*s*. 5*d*. per quarter over the first harvest-year, to 49*s*. 9*d*. over the second, 41*s*. 5*d*. over the third, and 42*s*. 8*d*. over the fourth. The lowest price reached was 36*s*. per quarter in the last week of 1835 and the first of 1836. And such was the distress suffered by the agricultural interest, as the result of abundant wheat-crops, and the low prices following, that Select Committees of the House of Lords, and of the House of Commons, respectively, were appointed to inquire into the matter; as now we have a Royal Commission to inquire into the distress caused, not by abundant, but by deficient crops, and large importations, though by no means such low prices as during the period of great abundance.

1832.—The records show considerably higher than average temperatures during October, November, December (1831), and January (1832); a great excess of rain in October, and about average amounts in November and December, but a deficiency in January. February and March were rather under average as to temperature, with fairly average amounts of rain. In April the temperature was rather over, in May rather under, in June rather over, in July rather under, and in August about average. There was a considerable deficiency of rain in April, May, and July, and again in September, but a considerable excess in June and August. Of this season, Tooke and Newmarch say that the winter was open, the spring of medium forwardness, the summer unsettled to the end of July, then fine to the end of August, *when heavy rains* damaged the crops still out. Of the

crops they say they were well harvested south of Yorkshire, and that the yield was abundant.

Thus this abundant crop was grown under the influence of a mild and rather wet winter, a spring of moderate character, and a summer of only moderate temperatures, and with heavy rains excepting in July.

1833.—October, November, December, and February were for the most part considerably warmer than the average; but January and March were considerably colder, and April rather colder than the average. There had been a considerable amount of rain in October, and there was a great excess in February; but there was a deficiency in every other month from November to May inclusive. May was also unusually hot; June was hot, with a rather high total of rain, but greatly due to a violent gale about the middle of the month; July was rather, and August and September were considerably, below the average as to mean temperature; but the fall of rain during the three months was below average. Tooke and Newmarch say that the winter was open and wet, the spring wet excepting part of March; May, and most of June, fine; July showery, and the autumn mostly favourable for maturing and harvesting the crops, which were rather thin on the ground, but yielded well.

Thus this second of the series of abundant wheat-crops was grown in a season characterised by a generally mild and moderately wet winter and early spring, excepting January and March, which were cold. The remainder of the spring, and the early summer, were hot and mostly dry, and the rest of the season upon the whole favourable. The result was a high-yielding, but not bulky straw crop.

1834.—The mean temperature was higher than the average in every month from November 1833 to September 1834 inclusive, excepting in April, when the deficiency was not great. The excess was the most marked in the winter and in May, June, and July. November, December, and January were wet as well as warm; but February, March, April, and May were very dry, and June was scarcely average as to rainfall; in July there is a great excess indicated, which, however, was due to a tremendous storm, chiefly confined to London and twenty or thirty miles distant; in August there was again an excess, but in September a considerable deficiency. According to Tooke and Newmarch, the winter was mild and wet, the spring generally forward, the summer decidedly fine and dry, with high temperatures, and the autumn also fine; the wheat-crop remarkably abundant, got in well, of fine quality, and large yield.

This, which was one of the heaviest crops of wheat on record

was, therefore, grown in a season warmer than usual almost throughout, but especially in the winter and in the spring, excepting April; and, after an excess of rain in the winter, there was a considerable deficiency for four months, to the end of May,again a deficiency in June, but afterwards heavy rains, though with high temperatures.

1835.—The mean temperatures were higher than the average in every month from November to September inclusive, excepting in March, which was close upon the average. There was a considerable excess of rain in February, March, May, and June, but a considerable deficiency in October, November, December, January, April, July, and August. Tooke and Newmarch observe that the winter was as open, and as much marked by an absence of snow and frost as the three preceding winters; that the spring was upon the whole favourable to the wheat-crops; the summer brilliantly fine till the last week in June, and the wheat of extraordinary bulk and luxuriance. At the close of June heavy rains and high winds laid the crops; but bright breezy weather in July stayed the damage, though much did not ripen well. The rest of the season was fine. The wheat-crops were got in in excellent order; but, though bulky, they were decidedly inferior in both yield and quality to those of 1834.

To sum up in regard to these four consecutive seasons of abundant wheat-crops: it is seen that they were characterised by mild and open winters, upon the whole mild springs, and average or warmer than average summers—especially the last two of the four. In each season there were individual months of considerably more than average fall of rain, sometimes earlier, and sometimes later, and accordingly influencing the bulk of the crop. But each season was characterised by less than the average fall of rain during several months of the growing period, and this was particularly the case in the season of 1834, the one of the most extraordinary productiveness.

We now come to those of the seasons selected for illustration which have occurred since the commencement of the Rothamsted experiments, and the characters of which are, therefore, more within our own knowledge and observation. Of these we will take first the seasons of high productiveness, and take them in chronological order.

1854.—November (1853) was about, but December considerably below, the average as to temperature, indeed very severe; and portions of January and February were also severe, with heavy snow in January; but still the four months, January to April inclusive, each showed higher than the average mean temperature. In October (1853) there had been a great excess of rain, but during each of the six months from seed-time to the end of

April there was a considerable deficiency, and in all only hal the average fall, the total deficiency for the six months amount ing to about 5$\frac{1}{2}$ inches. In May there was a considerable exces of rain, which was very beneficial to the crops after the lon dry period. There was again a considerable deficiency in Jun and July, but an excess in August. As to temperature, Ma June, and July were all below the average; and August onl average. Of this season Tooke and Newmarch say—that Ma was cold and wet, June cold and ungenial, with less sun tha usual, July not one day of summer-heat; harvest ten days o a fortnight later than usual. And of the crop they say—th largest yield per acre that has been known for years, the large since 1834. Our own estimate of the crop over the Unite Kingdom was 35$\frac{7}{8}$ bushels, reckoned at 61 lbs. per bushel, th average of sixteen years being 28$\frac{1}{4}$ bushels.

Thus, the crop of 1854, which was very abundant both in cor and straw, was, after a severe winter period, grown under highe than average temperatures during the earlier, but lower durin the later, periods of growth; and with much less than the averag fall of rain in every month from seed-time to harvest, exceptin in May and August.

1857.—This was a season of much more than average pro ductiveness of corn, but of only about average growth of straw and it was characterised as follows:—The mean temperature o each of the six months, from November to April inclusive varied little from the average; but May was 1·5, June 3·6, Jul 2·9, and August 4·9 degrees warmer than the average. There ha been much less than the average fall of rain in October 1856 and in each of the seven months from November to May inclusiv there was a considerable deficiency of rain, excepting in January when there was an excess. The total deficiency during th seven months from seed-time to the end of May was abo 5$\frac{1}{4}$ inches. In June there was rather more than average, i July much less, but in August some excess.

Thus, this heavy corn- but not heavy straw-crop was obtaine under the influence of about average winter and early sprin but high summer temperatures; and, as in other cases of hig productiveness, there was here again much less than the averag fall of rain from seed-time to harvest, the only months of an excess being January, June, and August.

1863.—The harvest of 1863, not only yielded in our ow experimental wheat-field the most abundant crop since the com mencement of the experiments in 1843–4, but it probably gave th highest average produce per acre over the country at large sin 1834. With the exception of November (1862), which was u *usually cold*, every month from seed-time to the end of April wa *warmer than the average*. The excess was in December 4·4,

January 5·2, in February 3·4, in March 2·8, and in April 3 degrees. In October (1862) there had been a considerable excess of rain; but from that time to the end of May there was a considerable deficiency in every month excepting January, when there was an excess. The total deficiency in the seven months from November to May inclusive was more than 5 inches compared with the average. Thus, after an excess of rain in October, the winter and spring were not only unusually warm, but unusually dry, bringing the plant very early forward. May showed, however, rather lower, and June, July, and August only about, or but little higher than average temperatures. In June there was a considerable excess of rain, which, coming after such a long dry period, much aided growth, though it was sometimes so heavy as to lay the most forward and bulky crops. July and August were, on the other hand, considerably deficient in rain.

To sum up:—The conditions of season which gave the most abundant produce of both grain and straw throughout the thirty-six years of our experiments, and also much higher than average weight per bushel of grain, was characterised by an extremely mild winter and early spring, with much less than the average fall of rain during that period. The plant was thus brought early forward. Then came, in the early summer, a considerable amount of rain, after which there was a deficiency up to harvest. The temperature was only about the average in June and July, conducing to continued luxuriance rather than to early maturation; whilst August, the harvest month, was both warmer and drier than usual. The conditions were, therefore, those of a lengthened and almost unbroken course of gradual accumulation, with finally a favourable ripening period.

1864.—As has been seen, the crop of 1863 was probably the most abundant, both in corn and straw, of any among the thirty-six years of our observations—indeed the most abundant since 1834; and that of 1864, immediately succeeding it, is estimated to be only second to it in bulk and yield. October 1863 had been both warmer and drier than usual. Five out of the seven months, from November to May (1864) inclusive, were warmer than the average. The exceptions were January, which was only average, and February, which was 2·7 below average. With these prevailing higher than average temperatures during the winter and spring, there were nearly 4 inches less than the average fall of rain from seed-time to the end of May. The only month in which there was an excess was March, whilst in May there was only the average fall. June was rather below, July but little above, and August again rather below the average as to temperature; whilst in each of these three months there was much less than the *average fall* of rain.

Here again, then, the very large crop was produced under the

influence of warmer than average weather in early winter and in spring; only moderate or even lower than average summer temperatures; but much less than the average fall of rain from seed-time to harvest; every month being considerably deficient, excepting May, which was average, and March, in which alone there was an excess.

1868.—After a favourable seed-time, the early winter of 1867–8 was very variable as to temperature, including some warm, but more stormy, wet, snowy, and frosty weather. From February, inclusive, to after harvest, the temperature was almost always above the average, and greatly so in May, June, and July; whilst, after a considerable excess of rain in January, there was, in each month from February to July inclusive, excepting in April, an unusual deficiency.

The period of growth was, therefore, almost throughout one of drought, with high temperatures throughout both spring and summer. The result was a very early harvest, a not bulky, but a high-yielding crop on good and well-farmed soils, but a deficient one on light and poorly-farmed land.

1870.—The autumn of 1869, though frequently cold, bois terous, and inclement, was upon the whole not unfavourable fo getting in the seed. The winter and early spring were chang able, and upon the whole colder than the average. But from th beginning of April until harvest the weather was, with fe exceptions of short duration, warmer than usual, with a gre deficiency of rain. The combined heat and drought were ev more extreme during the months of May, June, and July, 186 than during the corresponding months in 1870; the mean te perature being notably higher in each of these months in 18 But in 1870 the deficiency of rain commenced a month earli and was greater than in 1868.

After a by no means favourable winter, followed by pr longed spring and summer drought and heat, the wheat-crop 1870 was deficient in straw, and also yielded less corn th that of 1868, but still considerably more than the average, high proportion of corn to straw, and high quality of grain.

Thus, out of the six years of highest productiveness througho the thirty-six seasons of our experiments, the three which ga the highest produce of all, and high produce of straw as well a corn, and also high quality of grain (1863, 1864, and 1854 were characterised by generally higher than average mean tem peratures during the winter and early spring (excepting the earl winter of 1853–4, which was severe), but generally only average or lower than average, summer temperatures. Indeed, June 185 was colder than June 1879. Each was also characterised by very much less than the average fall of rain from seed-time to harvest *there being in* no case an excess in more than two out of the

nine months from November to July inclusive. The other three seasons of high productiveness, 1857, 1868, and 1870, though they gave less corn than the foregoing, and very much less straw, were, nevertheless, seasons of considerably more than average produce of corn, and of high quality of grain. These less bulky, but high-yielding crops were grown under more variable winter conditions as to temperature, but under much higher both spring and summer temperatures, especially those of 1868 and 1870; whilst, with the higher temperature there was, as in the cases with lower temperature and more abundant crops, much less than the average fall of rain from seed-time to harvest, one or two months only showing an excess.

We now come to the consideration of the seasons selected for illustrating the characters of low productiveness, namely, 1816, 1853, 1860, and 1879. We will first refer to the last three, which come within the period of our own observations, and then compare the characters of the extraordinarily unproductive season of 1879 with those of the also extraordinarily unproductive one of 1816.

1853.—The winter was very unseasonably warm and also wet. There had been a great excess of rain in October and November, and fully average amounts in December and January, causing floods, and much land intended for wheat remained unsown. From February to September, inclusive, every month was colder than the average, excepting May and June, which were about average; and the deficiency was greater in the spring than in the summer. In April there was a great excess of rain; in May there were heavy snow-falls; in June there was an excess of rain; in July a very great, and in August some, excess; and in September about an average amount. The breadth of land under wheat was much reduced, and the crop was reported to be far inferior, both in quantity per acre and in quality, to that of any season for many years past.

Thus the conditions under which this very inferior crop was grown were—that the early winter had been unseasonably wet and warm, the land being generally saturated with water, and in many cases flooded; the spring was unseasonably cold, and also wet; and the summer was also upon the whole colder than the average, and very wet.

1860.—From November (which was about average as to temperature) to May, inclusive, the months were alternately much colder and warmer than the average, May being warmer. But June, July, August, and September were all unusually cold and sunless for the period; very much more so than in 1853. There had been an excess of rain in October and November, but from that time till the end of April only moderate amounts, with, however, snow in February, March, and April. There

was a great excess of rain in May, June, August, and September, and there was about an average amount in July. The harvest was very late. Wheat was in some localities not deficient in bulk, but generally very much damaged, yielding but a small proportion of grain, and that of very low quality.

The characteristics of this season, yielding a crop both late and much below the average, both in quantity and quality, were, then, a winter alternately very cold and very mild, and upon the whole wet, followed by a spring, summer, and autumn generally stormy, cold, wet, sunless, and unseasonable.

1879.—Of all the eleven months, from November to September inclusive, March alone showed about average mean temperature. Each of the others was colder than the average. The deficiency was in November 2·6, in December 5·5, in January 4·7, in February 0·5, in April 2·9, in May 4·1, in June 1·3, in July 3·5, in August 1, and in September 0·2 degree. Then as to the rainfall. There was an excess in every month of the eleven excepting December and March. In November the excess amounted to 1·05, in January to 0·59, in February to 2·32, in April to 0·90, in May to 1·36, in June to 2·39, in July to 1·12, in August to nearly 3 inches, and in September to 0·43 inch. The total excess over the period was more than 11 inches.

Thus, from seed-time to the harvest of 1879, there was a considerable deficiency of temperature, compared with the average, in every month excepting March. It is remarkable, however, that there was even a lower mean temperature in June 1854, a season of very great abundance, than in June 1879, the season of the worst crop known within the century. But it was by the continuity and excessive amount of the rainfall that the season of 1878–9 was especially characterised; the excess during the eleven months from November to September inclusive, being, as already said, more than 11 inches over the average; and the total amount was more than double that over the same period of some of the seasons of high productiveness.

It remains to compare the characters of the disastrous season of 1878–9, with those of 1815–16, to which period, by common consent, we must go back for a wheat-crop at all approaching in deficiency, both in quantity and quality, that of the season just past.

1816.—Each of the ten months from November 1815 to August 1816, inclusive, was colder than the average. The deficiency was—in November 4·3, in December 2·6, in January 0·8, in February 4·2, in March 1·7, in April 2·5, in May 3·2, in June 3·1, in July 4·6, and in August 4·6 degrees. The average deficiency over the ten months was 3·1 degrees; and the deficiency was the greatest in the months of more active growth and of maturation. Compared with 1878–9, December

January (1815–16) were not nearly so cold, but November, February, and March were colder in 1815–16. The mean temperatures of April and May were rather the higher in 1816; but those of June, July, and August were considerably lower in 1816 than in 1879. In fact, there is no instance of so low a temperature prevailing throughout these three summer months, in any other of the 108 years, the temperature for which Mr. Glashier has given us the record. In each of the seven months, November 1815 to May 1816 inclusive, the fall of rain was only about, or not much over, the average; there being only one-third of an inch of excess compared with the average over that period; whilst, during the same months of 1878–9, there was an excess of more than 4¼ inches, and an excess compared with 1815–16 of nearly 4 inches. In June 1816 there was an excess, in July a great excess, but in August only a slight excess of rain; the total excess in the three summer months being only 2·34 inches, whilst in 1879 it was 6·3 inches. Over the whole ten months from November to August inclusive, 1815–16 showed only a total excess of 2·68 inches, whilst the same period of 1878–9 showed an excess of 10·6 inches over the average of 63 years; and for the first nine months of 1879 a higher rainfall is recorded than in the corresponding period of any year of the sixty-three. In September 1879 there was considerably more rain than in September 1816. But afterwards, with a very late harvest in both cases, there was a considerable excess in 1816, and a considerable deficiency in 1879; and it is stated that, in 1816, some wheat was still out when the winter snows began.

Thus, from seed-time to the end of May, the season of 1815–16, though materially colder than the average, did not include such a severe period as that of the winter of 1878–9; whilst the fall of rain was very little over average, and very much below that of 1878–9. From seed-time up to the end of the spring, therefore, the season of 1815–16 was more favourable than that of 1878–9 as to temperature, and much more favourable as to rainfall—indeed, not specially unfavourable. During the three summer months, however, the temperature of 1816 was extremely low, and much lower than the corresponding though still low period of 1879. And, with the very low temperature of the summer of 1816, there was at the same time an excess of rain, but by no means so great an excess as in 1879; but subsequently, there was not only low temperature, but excess of rain in 1816, much damaging, and often preventing the harvesting of the crop.

There can be little doubt, therefore, that the season of 1879 was, from seed-time to the end of the summer, worse than that

of 1816. The latter suffered more from low temperature, but less from excess of rain during the summer. Both crops were, however, very late, and, for getting in the crop, the season of 1816 was much worse than that of 1879.

Having now pointed out the prominent characters as to temperature and rainfall of each of the fourteen seasons selected for illustration separately, it will be of interest, disregarding as much as possible the specialities of individual seasons, to consider the average character of classes of seasons, arranged according to the general character of their wheat crops. Accordingly, in Tables IV. V. and VI. the fourteen seasons are classified as stated below. There are given the average monthly mean temperatures and rainfall for each class, the difference between the result for each class and the average for a number of years, and the difference between the result for one class and another. The classes are as follows:—

Six years of high produce of both corn and straw; namely, 1832, 1834, 1835, 1854, 1863, and 1864.

Four years of high produce of corn, but not of straw; namely, 1833, 1857, 1868, and 1870.

Four years of very low produce; namely, 1816, 1853, 1860, and 1879.

Of course, the essential character of all averages is to eliminate extremes, and as the class of six seasons of high produce of both corn and straw includes individual seasons differing more widely from one another, both as to temperature and rainfall, than those within either of the other classes, the averages given in the table for that class cannot be taken as showing the character of the class without more of qualification than in the other cases. Admitting this, it will still be found that taking considerable periods of the seasons—from seed-time to the end of April, and from the beginning of May to harvest, for example—the averages do clearly bear out the general conclusion to which the consideration of the individual seasons has led, in regard to the main characteristics of those periods.

The first class includes the six seasons out of the fourt[illegible] which gave the heaviest total produce, corn and straw togeth[illegible] and it is to be observed that it is those seasons of greatest lu[illegible] riance of growth, which have also given the most corn per ac[illegible]

Confining attention, in the first place, to the period of [illegible] months, from November to April inclusive, in only one of [illegible] six seasons which go to make the average, were there t[illegible] months, and in four others there was only one month of the [illegible] of in any material degree lower than average temperature, [illegible] *in only one* season (1854) was there a really severe wi[illegible]

Mean Results for each Class, &c.

Months.	Six Seasons of much both Corn and Straw.	Four Seasons of much Corn, but not much Straw.	Four Seasons of Low Produce.	Average of 108 Years, 1771 to 1878.	Six Seasons of much Corn and Straw + or − Average of 108 Seasons.	Four Seasons of much Corn + or − Average of 108 Seasons.	Four Seasons of Low Produce + or − Average of 108 Seasons.	Six Seasons of much Corn and Straw + or − Four of much Corn.	Six Seasons of much Corn and Straw + or − Four of Low Produce.	Four Seasons of much Corn + or − Four of Low Produce.
				Monthly Mean Temperature at Greenwich.						
	°	°	°	°	°	°	°	°	°	°
October	51·4	50·1	50·1	49·6	+ 1·8	+ 0·5	+ 0·5	+ 1·3	+ 1·3	0·0
November	43·3	42·2	42·2	42·3	+ 1·0	− 0·1	− 0·1	+ 1·1	+ 1·1	0·0
December	41·4	39·5	38·7	39·2	+ 2·2	+ 0·3	− 0·5	+ 1·9	+ 2·7	+ 0·8
January	39·5	36·7	37·6	36·6	+ 2·9	+ 0·1	+ 1·0	+ 2·8	+ 1·9	− 0·9
February	39·3	40·2	35·4	38·7	+ 0·6	+ 1·5	− 3·3	− 0·9	+ 3·9	+ 4·8
March	42·4	40·8	40·0	41·1	+ 1·3	− 0·3	− 1·1	+ 1·6	+ 2·4	+ 0·8
April	47·4	47·0	43·7	46·1	+ 1·3	+ 0·9	− 2·4	+ 0·4	+ 3·7	+ 3·3
May	53·0	56·0	50·9	52·5	+ 0·5	+ 3·5	− 1·6	− 3·0	+ 2·1	+ 5·1
June	58·6	61·1	56·3	58·2	+ 0·4	+ 2·9	− 1·9	− 2·5	+ 2·3	+ 4·8
July	62·1	64·6	58·3	61·6	+ 0·5	+ 3·0	− 3·3	− 2·5	+ 3·8	+ 6·3
August	61·5	62·0	58·5	60·9	+ 0·6	+ 1·1	− 2·4	− 0·5	+ 3·0	+ 3·5
September	56·8	57·4	54·8	56·5	+ 0·3	+ 0·9	− 1·7	− 0·6	+ 2·0	+ 2·6
Average ..	49·7	49·8	47·2	48·6	+ 1·1	+ 1·2	− 1·4	− 0·1	+ 2·5	+ 2·6

TABLE V.—SUMMARY of RAINFALL of SELECTED SEASONS, classified according to the character of their WHEAT CROPS.

Mean Results for each Class, &c.

MONTHLY RAINFALL AT GREENWICH.

MONTHS.	Six Seasons of much both Corn and Straw.	Four Seasons of much Corn, but not much Straw.	Four Seasons of Low Produce.	Average of 63 Years, 1815–'77.	Six Seasons of much Corn and Straw + or − Average of 63 Seasons.	Four Seasons of much Corn + or − Average of 63 Seasons.	Four Seasons of Low Produce + or − Average of 63 Seasons.	Six Seasons of much Corn and Straw + or − Four of much Corn.	Six Seasons of much Corn and Straw + or − Four of Low Produce.	Four Seasons of much Corn + or − Four of Low Produce.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
October	2·39	2.09	2·91	2·8	+ 0·09	− 0·71	+ 0·11	+ 0·30	− 0·02	− 0·82
November	1·71	1·43	3·46	2·4	− 0·69	− 0·97	+ 1·06	+ 0·28	− 1·75	− 2·03
December	1·92	1·92	1·95	2·1	− 0·18	− 0·18	− 0·15	0·00	− 0·03	− 0·03
January	1·66	2·34	2·15	2·0	− 0·34	+ 0·34	+ 0·15	− 0·68	− 0·49	+ 0·19
February	1·10	1·41	2·01	1·5	− 0·31	− 0·09	+ 0·51	− 0·22	− 0·82	− 0·60
March	1·36	1·24	1·46	1·6	− 0·24	− 0·36	− 0·14	+ 0·12	− 0·10	− 0·22
April	0·66	1·24	2·24	1·7	− 1·04	− 0·46	+ 0·54	− 0·58	− 1·58	− 1·00
May	2·06	0·67	2·73	2·0	+ 0·06	− 1·33	+ 0·73	+ 1·39	− 0·67	− 2·06
June	2·17	1·41	3·81	1·9	+ 0·27	− 0·49	+ 1·91	+ 0·76	− 1·64	− 2·40
July	1·53	1·46	4·07	2·6	− 1·07	− 1·14	+ 1·47	+ 0·07	− 2·54	− 2·61
August	2·26	2·22	3·54	2·4	− 0·14	− 0·18	+ 1·14	+ 0·04	− 1·28	− 1·32
September	2·03	2·10	2·56	2·4	− 0·37	− 0·30	+ 0·16	− 0·07	− 0·53	− 0·46
Total	21·44	19·53	32·99	25·4	− 3·96	− 5·87	+ 7·49	+ 1·91	− 11·45	− 13·86

TABLE VI.—SUMMARY of RAINFALL of SELECTED SEASONS, classified according to the character of their WHEAT CROPS.

Mean Results for each Class, &c.

MONTHS.	Six Seasons of much both Corn and Straw.	Four Seasons of much Corn, but not much Straw.	Four Seasons of Low Produce.	Average of 55 Years, 1815–'69.	Six Seasons of much Corn and Straw + or − Average of 55 Seasons.	Four Seasons of much Corn + or − Average of 55 Seasons.	Four Seasons of Low Produce + or − Average of 55 Seasons.	Six Seasons of much Corn and Straw + or − Four of much Corn.	Six Seasons of much Corn and Straw + or − Four of Low Produce.	Four Seasons of much Corn + or − Four of Low Produce.
NUMBER OF DAYS ON WHICH 0·01 INCH OR MORE FELL AT GREENWICH.										
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
October	17	15	16	14	+ 3	+ 1	+ 2	+ 2	+ 1	− 1
November	11	10	17	13	− 2	− 3	+ 4	+ 1	− 6	− 7
December	15	14	19	12	+ 3	+ 2	+ 7	+ 1	− 4	− 5
January	14	16	18	12	+ 2	+ 4	+ 6	− 2	− 4	− 2
February	11	12	15	11	0	+ 1	+ 4	− 1	− 4	− 3
March	12	12	16	12	0	0	+ 4	0	− 4	− 4
April	7	14	15	11	− 4	+ 3	+ 4	− 7	− 8	− 1
May	12	5	14	11	+ 1	− 6	+ 3	+ 7	− 2	− 9
June	11	8	18	11	0	− 3	+ 7	+ 8	− 7	−10
July	8	9	18	11	− 3	− 2	+ 7	− 1	−10	− 9
August	10	10	18	11	− 1	− 1	+ 7	0	− 8	− 8
September	12	11	15	12	0	− 1	+ 3	+ 1	− 3	− 4
Total	140	136	199	141	− 1	− 5	+ 58	+ 4	− 59	− 63

month. With these few exceptions every other month of the six within each of the six seasons was either about average or over average, and in many cases very much over average as to temperature. Then as to the rainfall over the same period. In two of the seasons there were two months, and in two there was only one month, with any considerable excess of rain; whilst in the other two there was a deficiency in every month of the six. There were, therefore, in each of the six seasons, four, five, or six of these six months considerably drier than the average.

Next, as to the three months of May, June, and July. In two out of the six seasons, each of the three months was warmer than the average; in two each was colder than the average; and in the remaining two there were warmer and colder months, giving about average mean temperatures. As to the rain of these three months, in one out of the six years there was an excess in two of the three months, in four years in only one of the three, and in the other in neither month, an excess of rain. In one only of the six years was the total rain of the three months over the average; though, in three of the six seasons there was an excess in August.

With these explanations as to the elements making up the averages for the six seasons, it is to be observed that their average mean temperature was higher than that of 108 years, in every month of the twelve; but that the excess was very much greater in the months prior to May than in May and afterwards. In fact, the excess of mean temperature, taking the average of these six seasons of greatest productiveness of both corn and straw, is, notwithstanding the coldness of one or two winter or spring months in individual seasons, very much greater before May than afterwards, and it is, notwithstanding the high summer temperature of two of the years, quite insignificant afterwards. Turning now to the average rainfall: there is less than the average amount in nine months out of the twelve, and in the other three the excess is quite insignificant. It is remarkable, too, that the longest period of deficiency is from seed-time to the end of April; the period during which the temperatures were at the same time more in excess of the average. Further, the only month of any important amount of average excess is June; but Table VI. shows that there was, even in that month, not more than the average number of rainy days; whilst, of course, the higher temperatures, and the growth of the crops, at that period, would tend to counteract any otherwise evil effects from an excess.

Upon the whole, then, the seasons of highest productiveness of all were characterised by higher than average temperatures *during* most of the winter and the early spring. Some were

onsiderably warmer during the summer also, but the majority rere characterised by but little higher, or even lower, than verage temperatures in the summer. There was also a preailing deficiency of rain in the winter and spring, but a less narked deficiency in the summer.

The second class includes four seasons of high produce of orn, but of small produce of straw; and these seasons of high ield gave, on the average, less corn per acre than the seasons f greater total bulk of produce. Here, again, we have higher an average mean temperatures in every month but November d March, and then the deficiency was quite insignificant. ut, in these seasons of comparatively small total produce, but high yield of grain, the distribution of the excess of temperare is exactly the opposite of that observed in the case of the asons of heaviest gross produce. We have now comparatively significant excess of temperature in each month prior to May, it a considerable excess in May and the subsequent months, harvest. Then as to the rainfall: the only month of the elve in which there is any excess above the average is nuary; whilst it is in May, June, and July, the months of cess of temperature, that the deficiency is by far the most rked. It is in these three months too that the number of ny days is the most below the average.

In the cases, then, of small produce of straw, but of high portion of corn to straw, the result was associated with little re than fairly average conditions as to temperature during early stages of development of the plant, but with a considerle excess during the period of active above-ground growth, and maturation. There is, at the same time, though a considerle total deficiency of rain, a much more marked deficiency ring the periods of more active above-ground growth, and ripening, than during the earlier stages.

The third class of seasons, that including four of unusually w produce, shows very marked differences from either of the egoing. The averages show an actual deficiency of temperare in ten months out of the twelve; and in only one from ed-time to harvest was there an average excess of any imrtance, namely, in January. The deficiency of temperature as also more marked in the spring than in the winter, and ore in the summer than in the spring. With this great defiency of average temperature almost throughout, we have also, lmost throughout, an excess of rain; and the excess is very uch the greater in April and afterwards up to harvest than eviously. The number of rainy days is also greatly in excess, pecially in the summer months. Very low productiveness as, then, associated with both low temperatures and excess of

rain, especially during the periods of more active ab
growth and ripening.

An examination of the last three columns of the '
bring to light the differences, not between each class
and the average, but between class and class.

Comparing with one another the seasons of bo
total produce and highest produce of corn also, wi
comparatively low total produce, but of high yield
will be seen how prevailingly higher was the ave
temperature from seed-time to April inclusive, how l
it was in May and afterwards, and also how much
the fall of rain during May and afterwards, in the seas
total produce, than in those of high corn only. Tl
columns, again, show in a striking manner the dif
to temperature and rainfall which distinguish, in tl
the seasons of high produce of both corn and straw,
other those of high produce of corn but not of straw
seasons of unusually defective produce.

From the foregoing review and comparison of a
seasons of much more than average productiveness, a
of the greatest deficiency within a period of sixty-fo
would appear that mildness, and comparative dryness
rate considerable portions of the winter and ea
favouring root development, that is, an extended po
the soil by the plant, and a somewhat early start, hav
characteristics of the most productive seasons. These
fulfilled, prior to the period of more active above-grou
some of the most bulky, and at the same time the mos
grain crops, ripened under considerably higher th
summer temperatures also; but more of them ripened
of scarcely over, or even of under, average mean tem
and with, at the same time, but little, if any, less th
rage fall of rain during that period. Indeed, the facts
with those favourable early conditions, an abundan
high-yielding, crop may be obtained with only fairly
even under average, summer conditions. But there
doubt that, when high summer temperatures, withou
rain, do succeed upon the favourable conditions of ea
and of plant, above described, the proportion of gr
by the bulky crop will be the greater. It happen
that the two both bulky and high-yielding crops whi
in the warmer than average summers were the produc
before the period of our own observations. The less
somewhat less abundant in grain, but still high-yie
have, on the other hand, generally had less favourable
for winter root-development, and for early growth in

ve been developed under the influence of considerably higher an average summer temperature, with, at the same time, ficiency of rain almost throughout, and a considerable ficiency during the summer months.

The seasons of unusually deficient wheat-crops, on the other and, have been characterised by severe, or at any rate very angeable, winter and spring conditions, with, at the same me, generally an excess of rain during those periods, frequently turating the soil, causing much drainage, and discouraging ot-development, and early growth in spring. But the more triking characteristic of the bad seasons is a great deficiency of verage temperature, and especially a great excess of rain, from he period of active above-ground growth until harvest. The eason which gave the extremely deficient crop of 1816 was haracterised much more by unusually low temperatures through-ut, and especially during the summer months, than by any narked excess of rain excepting during those summer months, nd afterwards. The probably even still worse season of 1878–9, hough very cold in the winter, was by no means so defective in emperature throughout the spring and summer months as 1816; ut there was a great excess of rain, almost throughout the inter, spring, and summer, and a greater excess in the summer an in 1816, though much less afterwards. In a word, the crop f 1816 suffered more from low temperature than excess of rain, nd that of 1879 much more from an excess of rain than from w temperature, until the middle of the autumn, after which 316 continued wet, and 1879 became dry.

Lastly, it would appear that any defect of our climate in ppropriateness for the production of full and well-matured eat-crops is more connected with an excess of rain, and con-luent wetness of soil and humidity of atmosphere, than with y deficiency of average summer temperature.

—The Season of 1878–79, and the Experimental Wheat-Crops at Rothamsted.

Having illustrated the characters of a number of seasons of h and of low productiveness, and especially of the wretched of 1878–9, by reference to independent records, we now to a consideration of the characters of that season at thamsted, and of its effect upon the continuous wheat-crops re.

For twenty-seven years (1853–79 inclusive) the rainfall at thamsted has been measured by means of a gauge of one-usandth of an acre area (6 feet × 7 feet 3 inches), and also

by an ordinary 5-inch funnel-gauge, which had been in us some time previously.

The amount of the rainfall passing through 20 inche 40 inches, and 60 inches of soil and subsoil, in their natur state of consolidation, has also been determined for a number years; and the drainage waters so collected have frequently bee analysed. These "*drain-gauges*," also each of one-thousandt of an acre area, were constructed by digging down, and unde mining the soil, putting iron plates drilled with holes underneat and then building round the square of undisturbed soil in bri and cement. Reference to the amounts of water passing throug these *drain-gauges* will be made further on.

The following Table (VII.) shows the rainfall in inches, each of the twelve months from October 1878 to September 18 inclusive, as measured by both the large and the small rain-gau above referred to. It also shows the rainfall recorded, for t same period, at four stations which may be said roughly to north, south, east, and west of Rothamsted; namely, Bedfo Blackheath, Cambridge, and Oxford. For each place the numb of days in each month when 0·01 inch, or more, fell, is al given.

It will be observed that the registries of the large and the sm gauge at Rothamsted do not agree very closely during the in vidual winter months. This is chiefly accounted for by t accumulation or drifting of snow in the large gauge, a perhaps some loss of snow in the small gauge. During t other months the large gauge generally registers slightly m than the small; in those cases chiefly owing to measural quantities of mist, fog, hoar-frost, &c., being frequently co densed on its large surface when none was collected in t small gauge, or the quantities were too small for measuremen

But the remarkable fact brought out by the Table is, t both the amount of rain, and the number of days on wh 0·01 inch, or more, fell, were greater, and in some cases mu greater, at Rothamsted than at either of the other stations; a the excess was the most marked in the summer months. Taki the whole twelve months, and adopting the mean of the t Rothamsted measurements, the fall was 8·38 inches more th at Bedford, 6·73 more than at Blackheath, 6·12 more than Cambridge, and 7·18 more than at Oxford.

The actual amount of fall is not only very large, but it is excess compared with the average in almost every month, a in the summer months especially very greatly so. Out of 92 days of May, June, and July, more than 0·01 inch fell at Ro amsted on 65, leaving only 27 days without any rain, or w *less than that* amount; and, among the other places quoted,

TABLE VII.—RAINFALL in INCHES, and NUMBER of DAYS on which 0·01 inch, or more, fell, at ROTHAMSTED, BEDFORD, BLACKHEATH, CAMBRIDGE, and OXFORD. Twelve Months, OCTOBER, 1878, to SEPTEMBER, 1879, inclusive.

	Rothamsted.			Bedford.	Blackheath.	Cambridge.	Oxford.
	Large Gauge.	Small Gauge.	Mean.				
RAINFALL IN INCHES.							
October 1878.. ..	2·99	2·99	2·99	2·10	1·80	1·92	3·11
November „	4·55	4·73	4·64	3·50	3·53	4·66	2·28
December „	1·60	1·57	1·59	1·46	1·32	1·09	1·51
January 1879.. ..	2·85	2·46	2·66	2·25	2·47	1·98	3·00
February „	3·80	3·74	3·77	2·90	3·95	2·75	3·31
March „	1·18	1·09	1·13	1·00	0·70	0·88	0·88
April „	2·79	2·61	2·70	1·80	2·64	2·18	2·45
May „	3·48	3·46	3·47	3·25	3·37	3·32	2·71
June „	5·55	5·49	5·52	4·35	4·16	5·22	4·54
July „	4·24	4·17	4·20	4·20	3·62	3·49	3·38
August „	6·56	6·47	6·52	4·50	5·12	5·92	5·05
September „	3·13	3·07	3·10	2·60	2·88	2·76	2·89
3 months, Oct.–Dec.	9·14	9·29	9·22	7·06	6·65	7·67	6·90
3 months, Jan.–Mar.	7·83	7·29	7·56	6·15	7·12	5·61	7·19
3 months, April–June	11·82	11·56	11·69	9·40	10·17	10·72	9·70
3 months, July–Sept.	13·93	13·71	13·82	11·30	11·62	12·17	11·32
12 months..	42·72	41·85	42·29	33·91	35·56	36·17	35·11
NUMBER OF DAYS ON WHICH 0·01 INCH OR MORE FELL.							
October 1878.. ..	22	21	21	14	12	15	15
November „	22	23	23	17	15	21	16
December „	16	16	16	12	14	17	10
January 1879.. ..	13	13	13	7	10	12	9
February „	23	23	23	18	21	23	22
March „	14	14	14	10	14	17	13
April „	20	19	19	14	18	21	16
May „	18	18	18	16	17	19	16
June „	26	26	26	24	18	26	27
July „	21	21	21	22	18	22	19
August „	18	17	18	15	19	17	17
September „	14	14	14	14	14	13	15
3 months, Oct.–Dec.	60	60	60	43	41	53	41
3 months, Jan.–Mar.	50	50	50	35	45	52	44
3 months, April–June	64	63	63	54	53	66	59
3 months, July–Sept.	53	52	53	51	51	52	51
12 months..	227	225	226	183	190	223	195

number of the so-reckoned rainy days in those three months w exceeded only at Cambridge, though the total amount of ra there was less. In the night of August 2–3, a thunder-storm great severity occurred, during which 3 inches or more of ra fell within a very few hours. With such a season we could viously expect nothing but disaster to the wheat-crop; and fr the comparisons given we should be prepared to find that injury was greater at Rothamsted than in many other places.

The next Table (VIII.) shows the produce on some selec plots in the permanent wheat-field at Rothamsted in 1879, co pared with the average on the same plots, and with the sa manures every year, over the previous twenty-seven years:—

TABLE VIII.—PRODUCE of WHEAT on selected PLOTS at ROTHAMST in 1879, compared with the AVERAGE of 27 YEARS.

	Dressed Corn.				Straw per Ac	
	Quantity per Acre.		Weight per Bushel.			
	Average 27 Years, 1852–'78.	1879.	Average 27 Years, 1852–'78.	1879.	Average 27 Years, 1852–'78.	18
	Bushels.	Bushels.	lbs.	lbs.	Cwts.	Cw
Plot 3. Unmanured	13½	4¾	57·9	52·5	11¾	
Plot 2. Farmyard-Manure	34⅛	16	60·1	56·8	32¾	2
Plot 7. Mineral manure and 400 lbs. ammonia-salts	33¼	16¼	59·5	56·7	33¾	2
Plot 8. Mineral manure and 600 lbs. ammonia-salts	36⅞	20½	59·2	56·5	40⅜	
Plot 9. Mineral manure and 550 lbs. nitrate soda	38¼*	22	59·2*	56·5	43⅛*	

* Average of 24 years only instead of 27, as the exact manures stated not applied to Plot 9 during the first 3 years of the 27.

We shall have to consider further on † whether, or in what gree, there was a tendency to diminished or to increased prod on these several plots from year to year due, irrespectively the influence of season, to gradual exhaustion on the one ha or to accumulation by the continuous application of the resp tive manures on the other. It will be sufficient here to attention to the great deficiency, both in the quantity and quality of the produce, in 1879, compared with the average,

† In a sequel to this paper, which will probably be published in the *number of this 'Journal.'*

every one of the plots, whether under conditions as to manuring tending to exhaustion or to accumulation.

It will be observed that the greatest proportional deficiency of corn was without manure, and with farmyard-manure; and that the deficiency was the less the higher the artificial manuring. Without manure, there certainly has been a gradual decline of produce from exhaustion; but it is remarkable that there were no less than nine other plots which, as well as the unmanured plot, gave less than 5 bushels of dressed corn in 1879.

The defect in weight per bushel of the dressed corn was great under all the conditions cited; but it was considerably greater without manure than with any of the selected manures.

Lastly, great as was the deficiency in the produce of corn, and in the weight per bushel of the dressed corn, under all the conditions, the proportional deficiency of straw was very much less. Indeed, it was but small with the higher artificial manuring.

It may be said that, from the beginning to the end of the season, the weather fought against the crop. In every month, from seed-time to harvest, excepting in March, the mean temperature was below, and frequently very much below, the average; and the total rainfall was more than 1½ time as much as the average. The winter was very cold and also wet, so that the soil was saturated with water, and there was nothing to tempt the roots to spread, or to penetrate deeply. The low temperature and the great excess of rain in every subsequent month (except March) perpetuated this condition. The aboveground development was, therefore, also weak and unhealthy. Thus, the plant, which luxuriates in a comparatively dry soil and climate, passed its whole existence under exactly opposite conditions; and the result was only what was to be expected.

It has of course long been known that an excess of wet is injurious to the wheat-crop; but it is only comparatively recently that one at least of the material causes of the adverse influence has been clearly made out: namely, the great loss of nitrogen carried off by drainage in the form of nitrates.

In a paper published in this 'Journal' in 1856, Professor Way showed by the analysis of the drainage-waters from several soils, of different description, and differently manured, that whilst in such waters scarcely any ammonia was to be found, there was a variable and sometimes a very large amount of nitric acid, which he considered in all probability due to the oxidation of the nitrogenous organic matter of manures. Judging, however, from the results he had obtained, showing the power of soils to absorb ammonia, he was unwilling to believe in the conversion of ammonia into nitric acid within the soil. He further said that, considering how *very* great in some cases the quantities

of nitric acid in the drainage-waters were—" we might be seriously impressed with the significance of the fact, were it not that we know that these waters are extreme instances, and that in all probability such a loss rarely if ever occurs in ordinary farming." And, he goes on to say that Mr. Paine, the drainage-water from whose soil had yielded so much nitric acid, was in the habit of using on his land large quantities of such substances as hair, horn shavings, woollen rags, &c., to which in all probability this large quantity of nitric acid is to be referred.

In our own experiments we had for many years found, especially in the case of grain-crops, that, of the nitrogen supplied in manure, a large proportion remained unrecovered in the increase of produce. It was found that when a given amount of nitrogen was supplied year after year, and the same description of crop was grown for a series of years in succession, generally less than half as much as had been supplied was recovered in the increase of crop. It was further found that, if the application of the nitrogenous manure were discontinued, only a very small proportion of the missing amount of nitrogen would be recovered each year in the succeeding crops.

At first we were disposed to consider that this loss of nitrogen of manure might, in part at least, be explained by reference to the vital actions of the plant itself, as it had been concluded by various experimenters that plants evolved nitrogen by their leaves during growth. But, reference to the brief history of the progress of knowledge on the subject given in our paper—" On the Growth of Barley for Twenty Years in Succession on the same Land "—(this 'Journal,' vol. ix., S.S., part 2, pp. 331 *et seq.*) will show that, in 1861, we had come to rely much more on accumulation within the soil, and on loss by drainage, to account for the missing amount of the nitrogen of manure; and that, as more and more evidence on these points was forthcoming, we attributed more and more of importance to drainage as a source of loss.

In the autumn of 1866, finding that Dr. Voelcker was desirous to investigate the question of land drainage, we gladly provided him with samples of the drainage-water from the differently manured plots in the experimental wheat-field, and also with full particulars of their history for the purposes of inquiry. The samples were collected at five different periods, and Dr. Voelcker gave a summary of the results of complete analyses of 65 samples of such drainage-waters of accurately known history, in a paper in the 'Journal of the Chemical Society of London' in 1871 (vol. xxiv., p. 276); and he gave the results more in detail, and with more of reference to their agricultural bearings, in a paper " On the Composition of Waters

of Land Drainage," published in this 'Journal' in 1874. Dr. Voelcker determined not only the ammonia and the nitric acid in the drainage-waters, but also the whole of the mineral constituents.

Dr. Frankland also, at his own request, was supplied with numerous samples, not only of the drainage-waters from the different plots of the permanent wheat-field, but of those collected at the depths of 20, 40, and 60 inches respectively, from the "*drain-gauges*" already described; and also of the rain-water collected in the large gauge at Rothamsted. In all he analysed nearly 70 samples of rain-water, and more than 100 of drainage-waters so collected. He determined in them the organic carbon, the nitrogen in the different forms of combination in which it existed, and the chlorine. His results are published in full in the Sixth Report of the Rivers Pollution Commission, presented to Parliament in 1874. In that Report we have a very complete history of the waters of Great Britain, both above ground and under ground. We have the composition of the rain, the changes it undergoes in passing over or through various geological strata, and its condition as it appears again in rivers and springs.

The dates of collection of the samples of drainage-waters analysed by Dr. Voelcker ranged from December 1866 to December 1868; and those of the rain and drainage-waters analysed by Dr. Frankland from January 1868 to February 1873. More recently, the investigation has been continued in the Rothamsted Laboratory, and we have now a large number of results, which will be made the subject of a paper very shortly. In the meantime it will be sufficient for our present purpose to draw some illustrations from the already published results of Dr. Voelcker and Dr. Frankland.

At the conclusion of our paper "On the Effects of the Drought of 1870" (vol. vii., s.s. part 1, of this 'Journal'), we were enabled, by the courtesy of Dr. Voelcker and Dr. Frankland, none of whose results were then published, to point out how very large might be the loss of nitrogen from the land in the winter after the application of ammonia-salts in the autumn. And in our paper on the "Growth of Barley for Twenty Years in Succession on the same Land," in this 'Journal,' vol. ix., s.s., part 2, p. 334 *et seq.*, 1873, will be found tabular summaries of their results, and also a discussion of them.

In the following Table (IX.) is given a summary of some of the results of Dr. Voelcker and Dr. Frankland, in a different form from that above referred to. The object of the arrangement now adopted is, not only to indicate how great may be the loss suffered by the passing away of the nitrogen of manures in the form of

TABLE IX.—COMPOSITION of the DRAINAGE-WATER collected a different PERIODS of the SEASON, from PLOTS differently manured BROADBALK FIELD, ROTHAMSTED; WHEAT every YEAR, com mencing 1844.

Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage-water. Abstract of Dr. Voelcker's, and Dr. Frankland's Results.

		Ammonia-salts Autumn Sown, Nitrate Soda Spring Sown.			
		From Autumn Sowing to Spring Sowing.		From Spring Sowing to next Autumn Sowing.	
		Number of Collections.	Nitrogen per 100,000 Drainage.	Number of Collections.	Nitrogen per 100,0 Drainage
Plot 5.	Mixed mineral manure alone	7	0·622	4	0·06
Plot 6.	Mixed mineral manure, and 200 lbs. ammonia-salts = 41 lbs. nitrogen	7	1·242	4	0·06
Plot 7.	Mixed mineral manure, and 400 lbs. ammonia-salts = 82 lbs. nitrogen	7	2·182	4	0·14
Plot 8.	Mixed mineral manure, and 600 lbs. ammonia-salts = 123 lbs. nitrogen	7	2·737	4	0·23
Plot 9.	Mixed mineral manure, and 550 lbs. nitrate-soda = 82 lbs. nitrogen	6	1·019	4	2·06

nitrates in the drainage, but to show how much greater is th loss during the winter than during the later periods of the season when the manures have been autumn-sown.

The results in the Table relate to a period when the ammoni salts were applied to the plots in question in the autumn, an the nitrate of soda only in the spring. In the first division given the average composition of all the drainage-waters co lected between the date of sowing the ammonia-salts in th autumn and that of sowing the nitrate in the spring; and i the second division the average of those collected after th sowing of the nitrate, and before the next autumn sowing.

Looking to the first division, relating to the samples collecte during the winter, after the autumn sowing of the ammonia-salt and comparing the results of plot 5 with mineral manure withou ammonia-salts, with those of plots 6, 7, and 8, which had th same mineral manures, but with more and more of ammoni salts in addition, it is seen that there was, not only much mor nitrogen as nitric acid in 100,000 parts of the drainage-wate

where ammonia-salts were applied than where they were not, but that there was a gradual increase in the amount thus drained away and lost, with the increase in the amount of ammonia-salts applied.

Comparing the figures relating to the same plots in the second division with those in the first, it will be noticed how very much less, indeed how very small, is the quantity of nitrogen as nitrates in a given quantity of the drainage-water collected after the conclusion of the winter period. Not only have the autumn-sown manures already been subject to a great loss during the winter, but vegetation is now more active, and more and more rapidly takes up and utilises the nitrates, and so serves to arrest their passage downwards. Further, with the increasing growth, and the increasing temperature, evaporation is increased, and the proportion of the rainfall which drains away is diminished. In fact, so far as can be judged from the data at command, the amount of water passing through the soil will, in ordinary seasons, be several times as much during the first four or five months after autumn-sowing and before the commencement of active above-ground growth, as afterwards to harvest. In the case of the autumn-sowing of the ammonia-salts there is, therefore, not only a much larger quantity of nitrogen as nitrates in a given quantity of drainage-water, but there is also a much larger quantity of water passing as drainage, during the winter than afterwards.

Lastly in regard to the results relating to the autumn-sown ammonia-salts, it will be observed that although the quantity of nitrogen as nitrates in a given quantity of the drainage-water collected after the winter, and after the commencement of more active growth, is very small, it is, as in the case of the samples collected during the winter, and sooner after the application, the greater, the greater the amount of ammonia-salts applied.

We have yet to notice the results obtained from the plot manured with nitrate of soda, which was always applied in the spring, and generally between the middle and the end of March. It is seen that the drainage from this plot was much richer in nitrates after the application of the nitrate in the spring than it was during the winter before the fresh application. Still, considering the great solubility of the nitrate, the little power of the soil to retain it, the fact that a crop had been grown and removed since the previous application, and the great quantity of drainage passing during the winter, the average amount of nitrogen as nitrates in the samples collected in the autumn and winter months is greater than would be expected compared with that from the plots manured with the ammonia-salts in the autumn. Nor is the average amount in the drainage collected

after the application of the nitrate so high as might be expected: though the amount has been found to be very high in individual cases of drainage collected soon after the spring dressing.

Lastly, to facilitate the appreciation of the significance of the results given in the Table, it may be observed that, for every inch of rain passing beyond the reach of the roots, and containing one part of nitrogen as nitrates per 100,000 parts of water, there will be a loss of rather more than 2¼ (2·26) lbs. of nitrogen per acre; corresponding to about 11 lbs. of the "ammonia-salts," or to about 14½ lbs. of nitrate of soda. And, as illustrating how very great may be the loss when heavy rain and much drainage follow soon after the application of heavy dressings of ammonia-salts or nitrate of soda, it may be mentioned that one sample of drainage-water collected early in January 1872, after the application of 600 lbs. of ammonia-salts early in November, was found by Dr. Frankland to contain so much nitrogen as nitrates as to represent a loss of 18 lbs. of nitrogen per acre, corresponding to about 86 lbs. of the "ammonia-salts," or to about 114 lbs. of nitrate of soda, provided an inch of rain had passed away as drainage of that strength; which, however, was probably not the case. Again, in one case of the Rothamsted analyses, the drainage-water collected on April 7th from the plot which had been dressed with 550 lbs. of nitrate of soda on March 10, contained so much nitrogen as nitrates as to represent a loss of about 15½ lbs. of nitrogen per acre, corresponding to about 76 lbs. of the "ammonia-salts," or to about 100 lbs. of nitrate of soda, provided that (which again was probably not the case) an inch of rain had passed as drainage of that strength.

It should be added that, besides nitrogen as nitrates and nitrites, land drainage-waters always contain more or less as ammonia or as organic nitrogen, but the quantity passing away in these forms is quite insignificant compared with that lost as nitrates.

In consequence of the very conclusive evidence of the great loss by drainage of the nitrogen of ammonia-salts applied in the autumn, especially in wet winters, it was decided, in the autumn of 1872, to devote one plot in the experimental wheat field to the application of the ammonia-salts in the spring. Accordingly, plot 15, which had for many years been manured with approximately the same mineral manures, and approximately the same amount of nitrogen, as plot 7, was selected; and, from that time, precisely the same mineral manures, and precisely the same amount of ammonia-salts were applied to plot 15 as to plot 7. To both plots the mineral manures were, as before, applied in the autumn; to plot 7 (as to all the other ammonia-plots), the ammonia-salts also were applied in the autumn, but to

plot 15 they were not applied until the spring. For the five crops, from 1873 to 1877 inclusive, this arrangement was continued. It happened that four out of the five seasons were wetter than the average, and especially during the winter months. The consesequence was that, in the two wettest seasons the result was very much against the autumn sowing; in two less excessively wet ones it was about equal; and, in the season of 1874 alone, the winter of which was dry, it was very decidedly in favour of autumn sowing. After the harvest of 1877, therefore, it was decided that plot 7, and all the other plots which had hitherto received ammonia-salts in the autumn, should not receive them until the spring, and that, for comparison with plot 7, plot 15 should now receive its ammonia-salts in the autumn.

The following Table (X.) shows the bushels of corn, and the weight of straw, and of total produce, obtained in each of the seven years, from 1873 to 1879 inclusive, by autumn sowing, and by spring sowing, respectively, of the ammonia-salts.

TABLE X.

Seasons.	Dates of Sowing Ammonia-salts.		Corn, Straw, and Total Produce per Acre.					
			Corn.		Straw.		Total Produce.	
	Autumn.	Spring.	Autumn Sown.	Spring Sown.	Autumn Sown.	Spring Sown.	Autumn Sown.	Spring Sown.
			Bushels.	Bushels.	lbs.	lbs.	lbs.	lbs.
1873	Oct. 18	Mar. 25	22	32⅝	2021	3079	3344	5031
1874	„ 28	„ 19	39⅜	29⅛	4645	2776	7094	4588
1875	„ 23	„ 23	25⅞	25½	3422	3204	5110	4915
1876	„ 30	„ 24	23½	25½	2212	2428	3793	4083
1877	„ 17	Apr. 11	19⅞	33⅛	1835	2788	3048	4795
1878	Nov. 3	Mar. 14	22⅛	31¼	3071	4952	4486	7017
1879	Oct. 15	„ 10	5⅜	16¼	906	3012	1275	4063
Averages	..	..	22½	27¾	2587	3177	4021	4927

It will be observed that, in 1874 alone, was the result decidedly in favour of autumn sowing. In 1873, 1877, 1878, and 1879, it was decidedly against autumn sowing; whilst, in 1875 and 1876, the difference was immaterial.

In Table XI. (page 36) is shown :—

1. The increase or diminution of produce by spring sowing.

2. The rainfall in each season, from the date of autumn sowing to that of spring sowing, and from that of spring sowing to the end of June, as measured by the large gauge at Rothamsted.

3. The amount of drainage passing through 60 inches of soil in the "drain-gauge" during the same periods.

As already said, we have no means of gauging the amount

TABLE XI.

SEASONS.	Dates of Sowing Ammonia-salts.		Produce More (+) or less (−) by Spring Sowing.			Rainfall, Large Gauge.		Drainage (60 I Drain Gauge	
	Autumn.	Spring.	Corn.	Straw.	Total.	From Autumn to Spring Sowing.	From Spring Sowing to end of June.	From Autumn to Spring Sowing.	Fr Spr Sow to e Ju
			Bushels.	lbs.	lbs.	Inches.	Inches.	Inches.	Inc
1873	Oct. 18	Mar. 25	+ 10⅝	+1058	+1687	18·53	4·39	11·45	0
1874	„ 28	„ 19	− 10¼	−1869	−2506	7·05	5·12	2·89	0
1875	„ 23	„ 23	− 0⅜	− 218	− 195	10·55	7·89	5·21	0
1876	„ 30	„ 24	+ 2	+ 216	+ 290	12·17	6·12	10·14	1
1877	„ 17	Apr. 11	+ 13¼	+ 953	+1747	22·01	4·90	15·78	0
1878	Nov. 3	Mar. 14	+ 9⅛	+1881	+2531	11·17	12·30	8·11	5
1879	Oct. 15	„ 10	+ 10⅞	+2106	+2788	15·05	12·86	13·09	4
Averages	..	..	+ 5¼	+ 590	+ 906	13·79	7·65	9·52	2

of drainage from the different plots in the experimental wheat-field. But the record of the amount of the rain passing throug[h] 60 inches of soil and subsoil in one of the "drain-gauges" de-scribed at p. 26, will at any rate give some idea of the charac-ters of the different seasons in regard to drainage. As the so[il] of the "drain-gauge" is without vegetation, the amounts [of] drainage passing through it during the winter, that is from th[e] date of autumn sowing to the date of spring sowing, will doubtle[ss] more nearly represent the relative, and in some degree the actu[al] amounts passing through the soil of the wheat-field during th[at] period than afterwards. But, after active vegetation has com-menced, the drainage would doubtless be proportionally less [in] the wheat-field than through the bare drain-gauge soil.

From what has been shown in the former part of this pap[er] it will be obvious that the exact differences in the amount [of] produce obtained by autumn and by spring sowing respectivel[y] in the different seasons, cannot be at all adequately explained [by] the abstract given of rainfall and drainage alone. To do this, it would be necessary to go into detail as to the distribution of the rain, the coincident temperatures, and the condition of pro-gress of the growing crop. But to bring prominently to view the effect of loss by drainage, it will be well to confine attention to the two extreme cases; the one in which the highest, and the other in which the lowest produce, of both corn and straw, was obtained after the autumn sowing of the ammonia-salts. These are 1874 and 1879.

In 1874, there was not only much more produce, both corn and straw, obtained by autumn than by spring sowing; but by autumn sowing there was then obtained the highest produce in

series, whether by autumn or by spring sowing. In 1879, the other hand, autumn sowing gave not only much less than ing sowing, but much less than in any of the other cases of ıer autumn or spring sowing.

The following summaries bring prominently into contrast produce of the two seasons, and the characters of the seasons mselves :—

PRODUCE.

	Ammonia-salts, Autumn Sown.			Ammonia-salts, Spring Sown.			More (+) or less (−) by Spring Sowing.		
	Corn.	Straw.	Total.	Corn.	Straw.	Total.	Corn.	Straw.	Total.
	Bushels.	lbs.	lbs.	Bushels.	lbs.	lbs.	Bushels.	lbs.	lbs.
'74	39⅜	4645	7094	29⅛	2776	4588	−10¼	−1869	−2506
79	5⅜	906	1275	16¼	3012	4063	+10⅞	+2106	+2788
'74 — '9	+34	+3739	+5819	+12⅞	−236	+525			

RAINFALL, and DRAINAGE through 60-INCH "DRAIN-GAUGE."

	From Autumn Sowing to Spring Sowing.		From Spring Sowing to end of June.		Total From Autumn Sowing to end of June.	
	Rainfall.	Drainage.	Rainfall.	Drainage.	Rainfall.	Drainage.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
'4	7·05	2·89	5·12	0·25	12·17	3·14
'9	15·05	13·09	12·86	4·95	27·91	18·04
74 — 79	− 8·00	−10·20	− 7·74	− 4·70	−15·74	−14·90

hus, in 1874, the autumn-sown ammonia-salts gave 39⅜ bushels orn and 4645 lbs. of straw ; and 10¼ bushels more corn, and 9 lbs. more straw, than the spring-sown ammonia. With heavy crop by autumn-sown ammonia, and much heavier n by the spring sown, there were only 7·05 inches of rain from date of autumn sowing to that of spring sowing, and only 9 inches of drainage through the 60-inch drain-gauge, during same period. Then again, from the date of spring sowing to end of June, there were only 5·12 inches of rain, and only 5 inch of drainage through the 60 inches of uncropped soil. would appear that the small amount of winter rain was suffiınt to aid the conversion of much of the ammonia of the manure

into nitric acid, and for its distribution through the soil, favour-ing root-development; but that it was not sufficient for much loss by drainage. On the other hand, it would seem that the small amount of rain after the spring sowing, when both the progress of vegetation and the increasing temperature would serve to increase evaporation, was insufficient for the necessary conversion and distribution of the nitrogen of the spring-sown ammonia-salts.

Contrast this result, and these conditions, with those of 1879. In 1879 we have only 5⅝ bushels of corn, and only 906 lbs. of straw, with the autumn-sown ammonia-salts; or 34 bushels less corn, and 3739 lbs. less straw, than by the same manures sown in the autumn for the crop of 1874. Coincidently with this result we have, for the season of 1879, 15·05 inches of rain, and 13·09 inches of drainage through 60 inches of soil, from the date of autumn sowing to that of spring sowing; or 8 inches more rain, and 10·2 inches more drainage, than over the same period for the crop of 1874. In 1879, however, we have 16¼ bushels of corn, and 3012 lbs. of straw, or 10⅞ bushels more corn, and 2106 lbs. more straw, by spring sowing than by autumn sowing; and there were from the date of spring sowing to the end of June 12·86 inches of rain, and 4·95 inches of drainage through 60 inches; or 7·74 inches more rain, and 4·7 inches more drainage than during the same perod in 1874. Further, whilst the drain-pipes in the experimental wheat-field did not run more than twice from the date of autumn sowing to that of spring sowing; in the season of 1873–4, in the corresponding period of 1878–9 they ran about twenty times; and again, whilst from the date of spring sowing to the end of June they did not run at all in 1874, they ran six or seven times during the corresponding period in 1879. It is remarkable, that there was even more straw, though there was not more total produce, by spring sowing in the wet season of 1879, than in the dry one of 1874.

There can be no doubt that, in the season of 1878–9, there was an enormous loss by drainage from the autumn-sown ammonia-salts, not only during the winter, but also more or less afterwards; and that there was also a considerable loss from the spring-sown ammonia. In the season of 1873–4, on the other hand, whilst there seems to have been a sufficiency of rain during the winter for the action of the autumn-sown manure, it would appear that there was an actual deficiency for the proper action of the spring-sown ammonia-salts; resulting in even rather less straw, though still much more corn, than was obtained under the conditions of loss by drainage in 1879.

The quantity of ammonia-salts annually applied to each of *these two plots* is estimated to contain 82 lbs. of nitrogen; and

the crops removed in the two years in question contained the following amounts of nitrogen :—

	Nitrogen in Produce per Acre.								
	Ammonia-salts, Autumn Sown.			Ammonia-salts, Spring Sown.			More (+) or less (−) by Spring Sowing.		
	Corn.	Straw.	Total.	Corn.	Straw.	Total.	Corn.	Straw.	Total.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1874	37·0	14·5	51·5	28·5	9·1	37·6	− 8·5	−5·4	−13·9
1879	6·6	5·7	12·3	17·6	13·8	31·4	+11·0	+8·1	+19·1
1874 + or − 1879	+30·4	+ 8·8	+39·2	+10·9	− 4·7	+ 6·2	..	..	..

The point of greatest interest is the contrast between the result obtained by autumn sowing in the dry season of 1874, and in the wet one of 1879. Whilst we have, in the produce of 1874, 51·5 lbs. of nitrogen, corresponding to 63 per cent. of the amount supplied, we have, in that of 1879, only 12·3 lbs., corresponding to only 15 per cent. of that supplied. In these calculations no allowance is made for the amount of nitrogen that the respective crops may have derived from the previously existing stores within the soil, irrespectively of the immediate supply by the ammonia-salts. It is obvious that, were any such allowance made, the result would appear even worse than is represented by the figures as they stand. It may be added, that such approximate estimates as we are able to make, founded on the amount of water passing through the 60-inch drain-gauge, and on the analyses of the drainage-waters collected from the autumn-sown plot, from the date of the autumn sowing up to harvest, would indicate an amount of loss of the supplied nitrogen by drainage sufficient to account, in great measure, for the defective yield.

With regard to the results relating to the spring sowing, it need only be noticed how much less of the nitrogen of the manure was recovered in the produce after spring sowing than after autumn sowing in the dry season of 1874; and how little more of the nitrogen of the spring-sown ammonia-salts was recovered in the crop in the too dry season of 1874, than in the very much too wet one of 1879, with all its loss by drainage.

The facts adduced can leave no doubt whatever that, independently of other adverse effects arising from low temperatures and excess of rain, the Rothamsted experimental wheat-crops of 1879 suffered very considerably from loss of the nitrogen of

the manures by drainage. The question remains—wl farmed and manured in the ordinary way would sul thing like the same degree from the same cause? ' of Professor Way, which have been referred to, cl that considerable loss may so arise when animal i manures, such as hair, horn shavings, woollen rag employed; and results obtained at Rothamsted show is a similar loss when vegetable nitrogenous manur rape-cake, are used. Further, the drainage water dunged plot in the experimental wheat-field at Rot sometimes found to contain a considerable amount of i but always very much less than that collected at the from adjoining plots receiving much less nitrogen but in the form of ammonia-salts or nitrate of sod therefore, it is to be assumed that the loss of the i manure by drainage in the past season was proportio greater in the experimental wheat-field at Rothamst the case of land farmed in the ordinary way, there theless, be no doubt that much of the land of the large must also have suffered great loss in the same v

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BRITISH ASSOCIATION,

SWANSEA, 1880.

SKETCH OF THE PROGRESS

OF

AGRICULTURAL CHEMISTRY;

ADDRESS

TO THE

CHEMICAL SECTION.

BY

J. H. GILBERT, PH.D., F.R.S., V.P.C.S., F.L.S.,

President of the Section.

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1890.

ADDRESS

TO THE

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BRITISH ASSOCIATION.

BY

J. H. GILBERT, *Ph. D.*, *F.R.S.*, *V.P.C.S.*, *F.L.S.*,

PRESIDENT OF THE SECTION.

Some of my predecessors in this Chair, whose duties as teachers of chemistry lead them to traverse a wide range of the subject every year, have appropriately and usefully presented to the Section a *résumé* of the then recent progress in the manifold branches of the science which have now such far-reaching ramifications. Such a course has, however, come to be of much less importance and interest of late years, since the systematic publication by the Chemical Society of abstracts of chemical papers in home and foreign journals as soon as possible after their appearance. Some, on the other hand, have confined attention to a department with which their own inquiries have more specially connected them. And, when the Council of the Association request a specialist like myself to undertake the Presidency of the Section, it is to be supposed they take it for granted that he will select for his opening address some branch of the subject with which he is known to be mainly associated.

But it seems to me that there is a special reason why I should bring the subject of Agricultural Chemistry before you on the present occasion. Not only is the application of chemistry to agriculture included in the title of this Section; but in 1837 the Committee of the Section requested the late Baron Liebig to prepare a report upon the then condition of Organic Chemistry, and it is now exactly forty years since Liebig presented to the British Association the first part of his report, which was entitled *Organic Chemistry in its Applications to Agriculture and Physiology*; and the second part was presented two years later, in 1842, under the title of *Animal Chemistry, or Organic Chemistry in its application to Physiology and Pathology*. Yet, so far as I am aware, no President of the Section has, from that time to the present, taken as the subject of his address the Application of Chemistry to Agriculture.

Appropriate as, for these reasons, it would seem that I, who have devoted a very large portion of the interval since the publication of Liebig's works, above referred

to, to agricultural enquiries, should occupy the short time that can be de such a purpose in attempting to note progress on that important subjec be readily understood that it would be quite impossible to condense limits of an hour's discourse anything approaching to an adequate either of the progress made during the last forty years, or of the existin tion of agricultural chemistry.

For what is agricultural chemistry? It is the chemistry of the atm the chemistry of the soil; the chemistry of vegetation; and the chen animal life and growth. And but a very imperfect indication of the a labour which has been devoted of recent years to the investigation of thes branches of what might at first sight seem a limited subject, will suffice to you how hopeless a task it would be to seek to do more than direct atten few points of special interest. Indeed, devoting to the purpose such le have been able to command, the more I have attempted to become ac with the vast literature which has been accumulated on the subject, t difficulty have I felt in making a selection of illustrations which should vey an idea of the limits, rather than of the extent, of the labour which expended, and of the results which have been attained, in agricultural

The works of Liebig to which I have referred have, as you all know, subject of a very great deal of controversy. Agricultural chemists, physiologists, and animal physiologists, have each vehemently opposed the conclusions of the author, bearing upon their respective branches. B part which has fallen to my own lot in these discussions qualifies me at al for others as well as myself, I would say that those who, having themsel fully investigated the points in question, have the most prominently from any special views put forward in those works, will—whether they cultural chemists, vegetable physiologists, or animal physiologists—be t admit how vast has been the stimulus, and how important has been the given to research in their own department, by the masterly review of th ing knowledge, and the bold, and frequently sagacious, generalisations the most remarkable men of his time!

Confining attention to researches bearing upon agriculture, it wil before attempting to indicate either the position established by Lie works, or the direction of the progress since made, to refer very brie early history of the subject.

From what we now know of the composition and of the sources of t tuents of plants, it is obvious that a knowledge of the composition of t sphere, and of water, was essential to any true conception of the main fe the vegetative process; and it is of interest to observe that it was alm taneously with the establishment, towards the end of the last century, knowledge as to the composition of the air and of water, that their mutua with vegetation were first pointed out. To the collective labours Scheele, Priestley, Lavoisier, Cavendish, and Watt, we owe the knowl common air consists chiefly of nitrogen and oxygen, with a little carb that carbonic acid is composed of carbon and oxygen; and that water is of hydrogen and oxygen; whilst Priestley and Ingenhousz, Sennebier a house, investigated the mutual relations of these bodies and vegetabl Priestley observed that plants possessed the faculty of purifying air v combustion or by the respiration of animals; and, he having discovere it was found that the gaseous bubbles which Bonnet had shown to b from the surface of leaves plunged in water consisted principally of tha genhousz demonstrated that the action of light was essential to the de of these phenomena; and Sennebier proved that the oxygen emitte from the decomposition of the carbonic acid taken up.

So far, however, attention seems to have been directed more promi the question of the influence of plants upon the media with which they rounded, than to that of the influence of those media in contributing creased substance of the plants themselves. Towards the end of the las and in the beginning of the present one, De Saussure followed up these

and in his work entitled, *Recherches Chimiques sur la Végétation*, published in 1804, he may be said to have indicated, if not indeed established, some of the most important facts with which we are yet acquainted, regarding the sources of the constituents stored up by the growing plant. De Saussure illustrated experimentally, and even to some extent quantitatively, the fact that in sun-light plants increase in carbon, hydrogen, and oxygen, at the expense of carbonic acid and of water; and in the case of his main experiment on the point, he found the increase in carbon, and in the elements of water, to be very closely in the proportion in which these are known to exist in the carbohydrates. He further maintained the essentialness of the mineral or ash constituents of plants; he pointed out that they must be derived from the soil; and he called attention to the probability that the incombustible constituents so derived by plants from the soil, were the source of those found in the animals fed upon them.

With regard to the nitrogen which plants had already been shown to contain, Priestley and Ingenhousz thought their experiments indicated that they absorbed free nitrogen from the atmosphere; but Sennebier and Woodhouse arrived at an opposite conclusion. De Saussure, again, thought that his experiments showed rather an evolution of nitrogen at the expense of the substance of the plant, than any assimilation of it from gaseous media. He further concluded, that the source of the nitrogen of plants was more probably the nitrogenous compounds in the soil, and the small amount of ammonia which he demonstrated to exist in the atmosphere.

Upon the whole, De Saussure concluded that air and water contributed a much larger proportion of the dry substance of plants than did the soils in which they grew. In his view a fertile soil was one which yielded liberally to the plant nitrogenous compounds, and the incombustible or mineral constituents; whilst the carbon, hydrogen, and oxygen, of which the greater proportion of the dry substance of the plant was made up, were at least mainly derived from the air and water.

Perhaps I ought not to omit to mention here that, each year for 10 successive years, from 1802 to 1812, Sir Humphry Davy delivered a course of lectures on the *Elements of Agricultural Chemistry*, which were first published in 1813, were finally revised by the author for the Fourth Edition in 1827, but have gone through several editions since. In those Lectures, Sir Humphry Davy passed in review and correlated the then existing knowledge, both practical and scientific, bearing upon agriculture. He treated of the influences of heat and light; of the organisation of plants; of the difference, and the change, in the chemical composition of their different parts; of the sources, composition, and treatment, of soils; of the composition of the atmosphere, and its influence on vegetation; of the composition and the action of manures; of fermentation and putrefaction; and finally of the principles involved in various recognised agricultural practices.

With the exception of these discourses of Sir Humphry Davy, the subject seems to have received comparatively little attention, nor was any important addition made to our knowledge in regard to it, during the period of about 30 years, from the date of the appearance of De Saussure's work in 1804 to that of the commencement of Boussingault's investigations.[1]

About 1834, Boussingault became, by marriage, joint proprietor with his brother-in-law, of the estate of Bechelbronn, in Alsace. His brother-in-law, M. Lebel, was both a chemical manufacturer and an intelligent practical farmer, accustomed to use the balance for the weighing of manures, crops, and cattle. Boussingault seems to have applied himself at once to chemico-agricultural research; and it was under these conditions of the association of 'practice with science' that the first laboratory on a farm was established.

From this time forward, Boussingault generally spent about half the year in Paris, and the other half in Alsace; and he has continued his scientific labours, sometimes in the city, and sometimes in the country, up to the present time. His

[1] Some reference should have been made in the text to the labours and writings of Dr. Carl Sprengel, late Professor of Agriculture at Brunswick, who made numerous analyses of agricultural materials, and published numerous papers in connection with Agricultural Chemistry, during a series of years, commencing about 1826.

first important contribution to agricultural chemistry was made in 1836, whe
he published a paper on the amount of nitrogen in different foods, and on th
equivalence of the foods, founded on the amounts of nitrogen they contained;
and he compared the results so arrived at with the estimates of others founde
on actual experience. Although his conclusions on the subject have doubtle
undergone modification since that time, the work itself marked a great advan
on previously existing knowledge, and modes of viewing the question.

In 1837, Boussingault published papers—on the amount of gluten in differe
kinds of wheat; on the influence of the clearing of forests on the diminution o
the flow of rivers; and on the meteorological influences affecting the culture o
the vine. In 1838 he published the results of an elaborate research on th
principles underlying the value of a rotation of crops. He determined by analy
the composition, both organic and inorganic, of the manures applied to the lan
and of the crops harvested. In his treatment of the subject he evinced a cle
perception of the most important problems involved in such an inquiry; some o
which, with the united labours of himself and many other workers, have scarce
yet received an undisputed solution.

Thus, in the same year (1838), he published the results of an investigation o
the question whether plants assimilate the free or uncombined nitrogen of th
atmosphere; and although the analytical methods of the day were inadequate t
the decisive settlement of the point, his conclusions were in the main those whi
much subsequent work of his own, and much of others also, has served to confir

As a further element of the question of the chemical statistics of a rotation
crops, Boussingault determined the amount and composition of the residues
various crops; also the amount of constituents consumed in the food of a co
and of a horse respectively, and yielded in the milk and excretions of the co
and in the excretions of the horse. Here, again, the exigencies of the investi
gation he undertook were beyond the reach of the known methods of the tim
Indeed, rude as the art of agriculture is generally considered to be, the scienti
elucidation of its practices requires the most refined, and very varied, metho
of research; and a characteristic of the work of Boussingault may be said to b
that he has frequently had to devise methods suitable to his purpose, before
could grapple with the problems before him.

In 1839, chiefly in recognition of his important contributions to agricultu
chemistry, Boussingault was elected a member of the Institute; and in 187
thirty-nine years later, the Council of the Royal Society awarded to him t
Copley Medal, the highest honour at their disposal, for his numerous and vari
contributions to science, but especially for those relating to agriculture.

The foregoing brief historical sketch is sufficient to indicate, though but
broad outline, the range of existing knowledge on the subject of agricultu
chemistry prior to the appearance of Liebig's memorable work in 1840. It will
seen that some very important and indeed fundamental facts had already been es
blished in regard to vegetation, and that Boussingault had not only extended
quiry on that subject, but he had brought his own and previous results to bear u
the elucidation of long-recognised agricultural practices. There can be no dou
that the data supplied by his researches contributed important elements to the b
of established facts upon which Liebig founded his brilliant generalisations. A
cordingly, in 1841, Dumas and Boussingault published, jointly, an essay wh
afterwards appeared in English under the title of *The Chemical and Physiolog
Balance of Organic Nature*; and, in 1843, Boussingault published a larger wo
which embodied the results of many of his own previous original investigatio

But there can be no doubt that the appearance of Liebig's two works, wh
were contributions made in answer to a request submitted to him by the commit
of this Section of the British Association, constituted a very marked epoch in
history of the progress of agricultural chemistry. In the treatment of his subj
he not only called to his aid the previously existing knowledge directly bear
upon it, but he also turned to good account the more recent triumphs of orga
chemistry, many of which had been won in his own laboratory. Further, a ma
feature of his expositions was the adoption of what may be called the stati

method—I use the word statistical rather than quantitative, as the latter expression has its own technical meaning among chemists, which is not precisely that I wish to convey.

It seems that, notwithstanding the conclusive evidence afforded by the direct experiments of De Saussure and his predecessors, vegetable physiologists continued to hold the view that the humus of the soil was the source of the carbon of vegetation. Not only did Liebig give full weight to the evidence of the experiments of De Saussure and others, and illustrate the possible or probable transformations within the plant by facts already established in organic chemistry, but he demonstrated the utter impossibility of humus supplying the amount of carbon assimilated over a given area. He pointed out that humus itself was the product of previous vegetable growth, and that it could not therefore be an original source of carbon; and that, from the degree of its insolubility, either in pure water or in water containing alkaline or earthy bases, only a small portion of the carbon assimilated by plants could be derived from the amount of humus that could possibly enter the plant in solution. He maintained that, so far as humus was beneficial to vegetation at all, it was only by its oxidation, and a consequent supply of carbonic acid within the soil; a source which he considered only of importance in the early stages of the life of a plant, and before it had developed and exposed a sufficient amount of green surface to the atmosphere to render it independent of soil supplies of carbonic acid.

With regard to the hydrogen of plants, at any rate that portion of it contained in their non-nitrogenous products, he maintained that its source must be water; and that the source of the oxygen was either that contained in carbonic acid or that in water.

With regard to the nitrogen of vegetation, both from the known characters of free nitrogen, and as he considered a legitimate deduction from direct experiments, he argued that plants did not take up free or uncombined nitrogen, either from the atmosphere, or dissolved in water and so absorbed by the roots. The source of the nitrogen of vegetation was, he maintained, ammonia; the product of the putrefaction of one generation of plants and animals affording a supply for its successors. He pointed out that, in the case of a farm receiving nothing from external sources, and selling off certain products, the amount of nitrogen in the manure derived by the consumption of some of the vegetable produce on the farm itself, together with that due to the refuse of the crops, must always be less than was contained in the crops grown; and he concluded that though the quantity so returned to the land was important, a main source of the nitrogen assimilated over a given area was that brought down from the atmosphere in rain.

There can be no doubt that, owing to the limited and defective experimental evidence then at command on the point, Liebig at that time (as he has since) greatly over-estimated the amount of ammonia available to vegetation from that source. In Boussingault's '*réclamation*' already referred to, he gave much more prominence to the importance of the nitrogen of manures. In Liebig's next edition (in 1843) he combated the notion of the relative importance of the nitrogen of manures; maintained, in opposition to the view put forward in his former edition, that the atmosphere afforded a sufficient supply of nitrogen for cultivated as well as for uncultivated plants; that the supply was sufficient for the cereals as well as for leguminous plants: that it was not necessary to supply nitrogen to the former; and he insisted very much more strongly than formerly on the relative importance of the supply of the incombustible, or, as he designated them, the 'inorganic' or 'mineral,' constituents.

As to the incombustible or mineral constituents themselves, Liebig adduced many illustrations in proof of their essentialness. He called attention to the variation in the composition of the ash of plants grown on different soils; and he assumed a greater degree of mutual replaceability of one base by another, or of one acid by another, than could be now admitted. He traced the difference in the mineral composition of different soils to that of the rocks which had been their source; *and he seems to have* been led by the consideration of the gradual *action of 'weathering,' in rendering* available the otherwise locked-up stores, to

attribute the benefits of fallow exclusively to the increased supply of t
bustible constituents which would, by its agency, be brought into a cc
which they could be taken up by plants.

The benefits of an alternation of crops Liebig considered to be in part
by the influence of the excreted matters from one description of crop
growth of another. He did not attach weight to the assumption that su
would be directly injurious to the same description of crop; but he
rather that the matters excreted were those which the plant did not
would therefore be of no avail to the same description of plant, but w
use to another. He, however, attributed much of the benefits of a 1
different mineral constituents being required from the soil by the respec

Treating of manure, he laid the greatest stress on the return by it of
and the phosphates removed by the crops. But he also insisted on the i
of the nitrogen, especially that in the liquid excretions of animals, and c
the methods of treatment of animal manures by which the ammonia w
to be lost by evaporation. It is curious and significant, however, that s
passages in his first edition, in which he the most forcibly urges the va
nitrogen of animal manures, are omitted in the third and fourth editio

The discussion of the processes of fermentation, decay, and putrefa
that of poisons, contagions, and miasms, constituted a remarkable and
part of Liebig's first report. It was the portion relating to poisons, c
and miasms, that he presented to this Section as an instalment, at the
the Association held at Glasgow in 1840. It was in the chapters rela
several subjects here enumerated that he developed so prominently his vi
influence of contact in inducing chemical changes. He cited ma
transformations, other than those coming under either of the heads in q
illustration of his subject; and he discussed with great clearness the dif
ditions occurring, and the different results obtained, in various process
the different modes of fermenting beer, the fermentation of wine fro
kinds of grapes, the production of acetic acid, &c. As is well known,
a purely chemical explanation for the phenomena involved in ferment
further maintained that the action of contagions was precisely simila
latest writings on the subject (in 1870), he admits some change of vie
is by no means easy to decide exactly how much or how little of modi
would wish to imply.

Liebig's second report, presented at the meeting of this Associati
and published under the title of *Animal Chemistry, or Organic Chem*
applications to Physiology and Pathology, perhaps excited even more att
his first, and, probably from the manner as much as from the matter,
great deal of controversy, especially among physiologists and
Liebig was severe upon what he considered to be a too exclusive a
morphological characters in physiological research, and at any rate
attention to chemical phenomena, and, so far as these were invest
inadequate treatment of the subject according to strictly quantitative

He combated the view that nervous action, as such, could be a sou
of the heat of the body; and he adduced numerous illustrations and c
in support of the view that the combustion of carbon and hydrogen in
was sufficient to account for, and was the only source of, animal heat.

He compared and contrasted the general composition of plants an
In accordance with Mulder, he pointed out that whilst plants formed
genous bodies which they contain from carbonic acid, water, and
animals did not produce them, but received them ready-formed in thei
food; that, in fact, the animal begins only where the plant ends.
beyond Mulder, and beyond what had then, or has since, been esta
maintained the identity in composition of the admittedly analogous n
compounds in plants and in the blood of animals.

Omitting the fat which the carnivora might receive in the animals
sumed, he stated the characteristic difference between the food of car
herbivora to be, that the former obtained the main proportion of their

material from the waste of tissue; whilst the latter obtained a large amount from starch, sugar, &c. These different conditions of life accounted for the comparative leanness of carnivora and fatness of herbivora.

He maintained that the vegetable food consumed by herbivora did not contain anything like the amount of fat which they stored up in their bodies; and he showed how nearly the composition of fat was obtained by the simple elimination of so much oxygen, or of oxygen and a little carbonic acid, from the various carbo-hydrates. Much less oxygen would be required to be eliminated from a quantity of fibrine, &c., containing a given amount of carbon, than from a quantity of carbo-hydrates containing an equal amount of carbon. The formation of fatty matter in plants was of the same kind; it was the result of a secondary action, starch being first formed from carbonic acid and water.

He concluded from the facts adduced that the food of man might be divided into the *nitrogenised* and the *non-nitrogenised* elements. The former were capable of conversion into blood, the latter incapable of such transformation. The former might be called the *plastic elements of nutrition*, the latter *elements of respiration.* From the plastic elements, the membranes and cellular tissue, the nerves and brain, cartilage, and the organic part of bones, could be formed; but the plastic substance must be received ready-made. Whilst gelatine or chondrine was derived from fibrine or albumen, fibrine or albumen could not be reproduced from gelatine or chondrine. The gelatinous tissues suffer progressive alteration under the influence of oxygen, and the materials for their re-formation must be restored from the blood. It might, however, be a question whether gelatine taken in food might not again be converted into cellular tissue, membrane, and cartilage, in the body.

At that time, adopting and attaching great importance to Mulder's views in regard to proteine, he says:—'All the organic nitrogenised constituents of the body, how different soever they may be in composition, are derived from proteine. They are formed from it by the addition or substraction of the elements of water or of oxygen, and by resolution into two or more compounds.'

He seeks to trace the changes occurring in the conversion of the constituents of food into blood, of those of blood into the various tissues, and of these into the secretions and excretions.

He states that the process of chymification takes place in virtue of a purely chemical action, exactly similar to those processes of decomposition or transformation which are known as putrefaction, fermentation, or decay. Thus, the clear gastric juice contains a substance in a state of transformation, by the contact of which with the insoluble constituents of the food they are rendered soluble, no other element taking any share in the action excepting oxygen and the elements of water. All substances which can arrest the phenomena of fermentation and putrefaction in liquids, also arrest digestion when taken into the stomach. Putrefying blood, white of egg, flesh, and cheese, produce the same effects in a solution of sugar, as yeast or ferment; the explanation being, that ferment, or yeast, is nothing but vegetable fibrine, albumen, or caseine, in a state of decomposition.

Referring to the derivation of the animal tissues, he says they all contain, for a given amount of carbon, more oxygen than the nitrogenous constituents of blood. In hair and gelatinous membrane there is also an excess of nitrogen and hydrogen, and in the proportions to form ammonia. We may suppose an addition of these elements, or a substraction of carbon, the amount of nitrogen remaining the same. The gelatinous substance is not a compound of proteine; it contains no sulphur, no phosphorus; and it contains more nitrogen, or less carbon, than proteine.

He next, as he says, attempts to develop analytically the principal metamorphoses which occur in the animal body. He adds that the results have surprised himself no less than they will others, and have excited in his own mind the same doubts as others will conceive. He nevertheless gives them, because he is convinced that the method by which they have been obtained is the only one by which we can hope to acquire an insight into the nature of organic processes.

Referring to the animal secretions, he argues that they must contain the products of the *metamorphosis of the* tissues. He says a starving man with severe *exertion secretes more urea than* the most highly fed individual in a state of rest

and he combats the idea that the nitrogen of the food can pass into urea without having previously become part of an organised tissue.

Having shown the chemical relations of bile and urine to the proteine bodies, he illustrates, by formulæ, the connection between allantoine and the constituents of the urine of animals that respire. He insists that in the herbivora the carbo-hydrates must take part in the formation of bile; and he calculates the number of equivalents of proteine, starch, oxygen, aud water, which would yield a given number of equivalents of urea, choleic acid, ammonia, and carbonate acid. The non-nitrogenous constituents in the food of the herbivora retard the metamorphosis of the nitrogenous bodies, rendering this less rapid than in the carnivora. It may be said that proteine, starch, and oxygen, give the secretions and excretions—carbonic acid by the lungs, urea and carbonate of ammonia by the kidneys, choleic acid by the liver. It is the study of the phenomena which accompany the metamorphoses of the food in the organism, the discovery of the share which the atmosphere and the elements of water take in these changes, by which we shall learn the conditions necessary for the production of a secretion or of an organised part.

He traces the possible formation of taurine from caffeine or asparagine by their assumption of oxygen and of the elements of water. And, from the composition of the vegetable alkaloids, he suggests the possibility of their taking a share in the formation of new, or the transformation of existing, brain and nervous matter.

Finally, in reference to these various illustrations and considerations, he says, however hypothetical they may appear, they deserve attention in so far as they point out the way which chemistry must pursue if she would really be of service to physiology and pathology. Chemistry, he says, relates to the conversion of food into the various tissues and secretions, and to their subsequent metamorphosis into lifeless compounds.

After this lapse of time, it will certainly be granted that, quite irrespectively of the admissibility or otherwise of the particular illustrations adduced, or of the truth or error of any of the conclusions drawn—and some at least are so true that they seem to us now all but truisms, and you may be disposed to ask me why I should tell you over again a story so often told before—there is no doubt that Liebig's manner of treating the subject did exert an immense influence, by stimulating investigation, by fixing attention on the points to be investigated, and on the methods that must be followed, and thus, by leading to the establishment or the correction of any special views he put forward, and to a vast extension of our knowledge on the complicated questions involved.

In the third part of Liebig's second volume he treats of the phenomena of motion in the animal organism. It is to his views in regard to one aspect only of this very wide and very complicated subject, that I propose to call your attention here, as it is chiefly in so far as that aspect is concerned that the question is of interest from the point of view of the agricultural chemist. He says:—

'We observe in animals that the conversion of food into blood, and the contact of the blood with the living tissues, are determined by a mechanical force, whose manifestation proceeds from distinct organs, and is effected by a distinct system of organs, possessing the property of communicating and extending the motion which they receive. We find the power of the animal to change its place and to produce mechanical effects by means of its limbs dependent on a second similar system of organs or apparatus.'

He points out that the motion of the animal fluids proceeds from distinct organs (as for example, that of the blood from the heart), which do not generate the force in themselves, but receive it from other parts by means of the nerves; the limbs also receive their moving force in the same way. He adds: 'Where nerves are not found, motion does not occur.' Again:—

'As an immediate effect of the manifestation of mechanical force, we see that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied *by the entrance* of a foreign body (oxygen) into the composition of the *muscular fibre*. . .; and all experience proves that this conversion of living

muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion.' He adds that a rapid transformation of muscular fibre determines a greater amount of mechanical force, and that conversely a greater amount of mechanical motion determines a more rapid change of matter.

'The change of matter, the manifestation of mechanical force, and the absorption of oxygen, are, in the animal body, so closely connected with each other that we may consider the amount of motion and the quantity of living tissue transformed as proportional to the quantity of oxygen inspired and consumed in a given time by the animal.' Again:—

'The production of heat and the change of matter are closely related to each other; but although heat can be produced in the body without any change of matter in living tissues, yet the change of matter cannot be supposed to take place without the co-operation of oxygen.'

Further, on the same point:—'The sum of force available for mechanical purposes must be equal to the sum of the vital forces of all tissues adapted to the change of matter. If, in equal times, unequal quantities of oxygen are consumed, the result is obvious in an unequal amount of heat liberated, and of mechanical force. When unequal amounts of mechanical force are expended, this determines the absorption of corresponding and unequal quantities of oxygen.'

Then, more definitely still, referring to the changes which takes place coincidently with the exercise of force, and to the demands of the system for repair accordingly, he says:—

'The amount of azotised food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed. The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time. The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine. The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine, whether the mechanical force has been employed in the voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera.'

Thus, apparently influenced by the physiological considerations which have been adduced, and notwithstanding in some passages he seemed to recognise a connection between the total quantity of oxygen inspired and consumed and the quantity of mechanical force developed, Liebig nevertheless very prominently insisted that the amount of muscular tissue transformed—the amount of nitrogenous substance oxidated—was the measure of the force generated. He accordingly distinctly draws the conclusion that the requirement for the azotised constituents of food will be increased in proportion to the increase in the amount of force expended.

It will be obvious that the question whether in the feeding of animals for the exercise of mechanical force, that is, for their labour, the demands of the system will be proportionally the greater for an increased supply of the nitrogenous or of the non-nitrogenous constituents of food is one of considerable interest and practical importance. To this point I shall have to refer further on.

So far, I have endeavoured to convey some idea of the state of knowledge on the subject of the chemistry of agriculture prior to the appearance of Liebig's first two works bearing upon it, and also briefly to summarise the views he then enunciated in regard to some points of chief importance. Let us next try to ascertain something of the influence of his teaching.

Confining attention to agricultural research, it may be observed that in 1843—that is, very soon after the appearance of the works in question—the Royal Agricultural Society of England first appointed a consulting chemist. At that date Dr. Lyon Playfair was elected; in 1848, Professor Way; and in 1858 Dr. Voelcker, who continues to hold the office with much advantage to that union of 'Practice with Science' which the Society by its motto recognises as so essential to progress. Also in 1843 there was established the Chemico-Agricultural Society of Scotland, which was, I believe, broken up, after it had existed between four and five years

because its able chemist, the late Professor Johnston, failed to find a remedy fo
potato disease. In 1845, the Chemico-Agricultural Society of Ulster was es
lished, and appointed as its chemist, Professor Hodges, who still ably perf
the duties of the office. Lastly, the very numerous '*Agricultural Experim
Stations*' which have been established, not only in Germany, but in most C
nental States, owe their origin directly to the writings, the teachings, and
influence, of Liebig. The movement seems to have originated in Saxony, w
Stöckhardt had already stimulated interest in the subject by his lectures an
writings. After some correspondence, in 1850-1, between the late Dr. Cr
and others on the one side, and the Government on the other, the first so-c
Agricultural Experimental Station was established at Möckern, near Leipzi
1851-2. In 1877, the twenty-fifth anniversary of the foundation of that ins
tion was celebrated at Leipzig, when an account (which has since been publi
was given of the number of stations then existing, of the number of che
engaged, and of the subjects which had been investigated. From that stati
statement we learn that in 1877 the number of stations was:—

In the various German States	74
In Austria	16
In Italy	10
In Sweden	7
In Denmark	1
In Russia	3
In Belgium	3
In Holland	2
In France	2
In Switzerland	3
In Spain	1
Total	122

Besides these 122 stations on the Continent of Europe, the United Stat
credited with 1, and Scotland also with 1.

Each of these stations is under the direction of a chemist, frequently wi
or more assistants. One special duty of most of them is what is called ma
or seed-or-feeding-stuff-control; that is, to examine or analyse, and report
such substances in the market; and it seems to have been found the inter
dealers in these commodities to submit their proceedings to a certain deg
supervision by the chemist of the station of their district.

But agricultural research has also been a characteristic feature of these
tutions. It is stated that the investigation of soils has been the prominent
at 16 of them; experiments with manures at 24; vegetable physiology
animal physiology and feeding experiments at 20; vine culture and wine-m
at 13; forest culture at 9; and milk-production at 11. Others, accord
their locality, have devoted special attention to fruit culture, olive cultu
cultivation of moor, bog, and peat land, the production of silk, the manu
of spirit, and other products.

Nor does this enumeration of the institutions established as the direct re
Liebig's influence, and of the subjects investigated under their auspices, co
the list either of the workers engaged, or of the work accomplished in agric
research. To say nothing of the labours of Boussingault, which commence
years prior to the appearance of Liebig's first work, and which are fortunat
at the service of agriculture, important contributions have been made by t
Professors Johnston and Anderson in Scotland, and in this country both by M
and Dr. Voelcker, each alike in his private capacity, and in fulfilment of his
as Chemist to the Royal Agricultural Society of England. Nor would it be
Mr. Lawes (who commenced experimenting first with plants in pots, and afte
in the field, soon after entering into possession of his property in 1834, and with
I have myself been associated since 1843), were I to omit in this place any n
of the investigations which have been so many years in progress at Roth

So much for the machinery; but what of the results achieved by all this activity in the application of chemistry to agriculture?

As I have already intimated, and as the foregoing brief statistical statement will have convinced you must be the case, it will be utterly impossible to give, on such an occasion as this, anything approaching to an adequate review of the progress achieved. Indeed, I have to confess that the more I have looked at the subject with the hope of treating it comprehensively, the more I have been compelled to substitute a very limited plan for the much more extended scheme which I had at first hoped to be able to fill up. I propose then to confine attention to a few special points, which have either some connection with one another, or to which recent results or discussions lend some special interest.

First as to the sources and the assimilation of the carbon, the hydrogen, and the oxygen of vegetation. From the point of view of the agricultural chemist, the hydrogen and the oxygen may be left out of view. For, if the cultivator provide to the plant the conditions for the accumulation of sufficient nitrogen and carbon, he may leave it to take care of itself in the matter of hydrogen and oxygen. That the hydrogen of the carbo-hydrates is exclusively obtained from water, is, to say the least, probable; and whether part of their oxygen is derived from carbonic acid, and part from water, or the whole from either of these, will not affect his agricultural practice.

With regard to the carbon, the whole tendency of subsequent observations is to confirm the opinion put forward by De Saussure about the commencement of the century, and so forcibly insisted upon by Liebig forty years later—that the greater part, if not the whole of it, is derived from the carbonic acid of the atmosphere. Indeed, direct experiments are not wanting—those of Moll, for example—from which it has been concluded that plants do not even utilise the carbonic acid which they may take up from the soil by their roots. However this may be, we may safely conclude that practically the whole of the carbon which it is the object of the cultivator to force the plants he grows to take up is derived from the atmosphere, in which it exists in such extremely small proportion, but nevertheless large actual, and constantly renewed amount.

Judging from the more recent researches on the point, it would seem probable that the estimate of one part of carbon, as carbonic acid, in 10,000 of air, is more probably too high than too low as an estimate of the average quantity in the ambient atmosphere of our globe. And, although this would correspond to several times more in the column of air resting over an acre of land than the vegetation of that area can annually take up, it represents an extremely small amount at any one time in contact with the growing plants, and it could only suffice on the supposition of a very rapid renewal, accomplished as the result, on the one hand of a constant return of carbonic acid to the atmosphere by combustion and the respiration of animals, and on the other of a constant interchange and equalisation among the constituents of the atmosphere.

It will convey a more definite idea of what is accomplished by vegetation in the assimilation of carbon from the atmosphere if I give, in round numbers, the results of some direct experiments made at Rothamsted, instead of making general statements merely.

In a field which has now grown wheat for thirty-seven years in succession, there are some plots to which not an ounce of carbon has been returned during the whole of that period. Yet, with purely mineral manure, an average of about 1,000 pounds of carbon is annually removed from the land; and where a given amount of nitrogenous manure is employed with the mineral manure, an average of about 1,500 pounds per acre per annum more is obtained; in all an average of about 2,500 pounds of carbon annually assimilated over an acre of land without any return of carbonaceous manure to it.

In a field in which barley has been grown for twenty-nine years in succession, quite accordant results have been obtained. There, smaller amounts of nitrogenous manure have been employed with the mineral manure than in the experiments with wheat above cited; but the increase in the assimilation of carbon for a given amount of nitrogen supplied in the manure is greater in the case of the barley than of the wheat.

With sugar-beet, again, larger amounts of carbon have been annually accumulated without the supply of any to the soil, but under the influence of a liberal provision of both nitrogenous and mineral manure, than by either wheat or barley.

Lastly, with grass, still larger amounts of carbon have been annually accumulated, without any supply of it by manure.

Many experiments have been made, in Germany and elsewhere, to determine the amount of the different constituents taken up at different periods of the growth of various plants. But we may refer to some made at Rothamsted long ago to illustrate the rapidity with which the carbon of our crops may be withdrawn from the atmosphere.

In 1847, we carefully took samples from a growing wheat crop at different stages of its progress, commencing on June 21, and in these samples the dry matter, the mineral matter, the nitrogen, &c., were determined. On each occasion the produce of two separate eighths or sixteenths of an acre was cut and weighed, so that the data were provided to calculate the amounts of the several constituents which had been accumulated per acre at each period. The result was that, whilst during little more than five weeks from June 21, there was comparatively little increase in the amount of nitrogen accumulated over a given area, more than half the total carbon of the crop was accumulated during that period.

Numerous experiments of a somewhat similar kind, made in another season 1856, concurred in showing that, whilst the carbon of the crop was more than doubled after the middle of June, its nitrogen increased in a much less degree over the same period.

Similar experiments were also made, in 1854 and in 1856, with beans. The general result was that a smaller proportion of both the total nitrogen and the total carbon was accumulated by the middle or end of June than in the case of the wheat; though the actual amount of nitrogen taken up by the beans was much greater, both before and after that date. The nitrogen of this leguminous crop increased in a much greater proportion during the subsequent stages of growth than did that of the gramineous crop; but the carbon increased in a larger proportion still, three-fourths or more of the total amount of it being accumulated after the middle of June.

I should say that determinations of carbon, made in samples of soil taken from the wheat field at different periods during recent years, indicate some decline in the percentage of carbon in the soils, but not such as to lead to the supposition that the soils have contributed to the carbon of the crops. Besides the amount of carbon annually removed, there will, of course, be a further accumulation in the stubble and roots of the crops; and the reduction in the total carbon of the soil, if such have really taken place, would show that the annual oxidation within it is greater than the annual gain by the residue of the crops.

Large as is the annual accumulation of carbon from the atmosphere over a given area in the cases cited, it is obvious that the quantity must vary exceedingly with variation of climatal conditions. It is, in fact, several times as great in the case of tropical vegetation—that of the sugar-cane for example. And not only is the greater part of the assimilation accomplished within a comparatively small portion of the year (varying of course according to the region), but the action is limited to the hours of daylight, whilst during darkness there is rather loss than gain.

But it is remarkable that whilst the accumulation of carbon, the chief gain of solid material, takes place under the influence of light, cell-division, cell-multiplication, increase in the structure of the plant, in other words, what, as distinguished from assimilation, vegetable physiologists designate as *growth*, takes place, at any rate chiefly, during the night; and is accompanied, not with the taking up of carbonic acid and the yielding up of oxygen, but with the taking up of oxygen and the giving up of carbonic acid. This evolution of carbonic acid during darkness must obviously be extremely small, compared with the converse action during daylight, coincidentally with which practically the whole of the accumulation of solid substance is accomplished. But, as the product of the night action is the same as in the respiration of animals, this is distinguished by vegetable physiologists as the respiration of plants.

I suppose I shall be considered a heretic if I venture to suggest that it seems in a

case inappropriate to apply the term *growth* to that which is associated with actual loss of material, and that the term *respiration* should be applied to so secondary an action as that as the result of which carbonic acid is given off from the plant. It may, I think, be a question whether there is any advantage in thus attemping to establish a parallelism between animal and vegetable processes; rather would it seem advantageous to keep prominently in view their contrasted, or at any rate complementary characteristics, especially in the matter of the taking up of carbonic acid and the giving up of oxygen on the one hand, and the taking in of oxygen and the giving up of carbonic acid on the other.

But it is obvious that in latitudes where there is comparatively continuous daylight during the periods of vegetation, the two actions—designated respectively assimilation and growth—must go on much more simultaneously than where there is a more marked alteration of daylight and darkness. In parts of Norway and Sweden, for example, where, during the summer, there is almost continuous daylight, crops of barley are grown with only from six to eight weeks intervening from seed-time to harvest. And Professor Schübeler, of Christiania, after making observations on the subject for nearly thirty years, has recently described the characteristics of the vegetation developed under the influence of short summers with almost continuous light. He states that, after acclimatisation, many garden flowers increase in size and depth of colour; that there is a prevailing tinge of red in the plants of the fjelds; that the aroma of fruits is increased, and their colour well developed, but that they are deficient in sweetness; and that the development of essential oils in certain plants is greater than in the same plants grown in other latitudes. Indeed, he considers it to be an established fact that light bears the same relation to aroma as heat does to sweetness.

In connection with this question of the characters of growth under the influence of continuous light, compared with those developed with alternate light and darkness, the recent experiments of Dr. Siemens on the influence of electric light on vegetation are of considerable interest.

In one series of experiments, he kept one set of plants entirely in the dark, a second he exposed to electric light only, a third to daylight only, and a fourth to daylight, and afterwards to electric light from 5 to 11 P.M. Those kept in the dark acquired a pale yellow colour, and died; those exposed to electric light only, maintained a light green colour, and survived; those exposed to daylight were of a darker green colour, and were more vigorous; and, lastly, those submitted to alternate daylight and electric light, and but a few hours of darkness, showed decidedly greater vigour, and, as he says, the green of the leaf was of a dark rich hue. He concluded that daylight was twice as effective as electric light; but that, nevertheless, 'electric light was clearly sufficiently powerful to form chlorophyll and its derivatives in the plants.'

In a second series of experiments one group of plants was exposed to daylight alone; a second to electric light during eleven hours of the night, and was kept in the dark during the day; and a third to eleven hours day, and eleven hours electric light. The plants in daylight showed the usual healthy appearance; those in alternate electric light and darkness were for the most part of a lighter colour; and those in alternate daylight and electric light far surpassed the others in darkness of green and vigorous appearance generally.

I have carefully considered these general descriptions with a view to their bearing on the question whether the characters developed under the influence of electric light, and especially those under the influence of almost continuous light, are more prominently those of assimilation or of growth; but I have not been able to come to a decisive opinion on the point. From some conversation I had with Dr. Siemens on the subject, I gather that the characteristics were more those of dark colour and vigour than of tendency to great extension in size. The dark green colour we may suppose to indicate a liberal production of chlorophyll; but if the depth of colour was more than normal, it might be concluded that the chlorophyll had not performed its due amount of assimilation work. In regard to this point, attention may be called to the fact that Dr. Siemens refers to the abundance of the blue or actinic rays in the electric arc, conditions which would not be supposed

specially to favour assimilation. On the other hand, the vigour, rather than characteristic extension in size, would seem to indicate a limitation of what is technically called growth, under the influence of the almost continuous light.

Among the numerous field experiments made at Rothamsted, we have many examples of great variation in depth of green colour of the vegetation growing on plots side by side under known differences as to manuring; and we have abundant evidence of difference of composition, and of rate of carbon-assimilation, coincidently with these different shades of colour. One or two instances will strikingly illustrate the point under consideration.

There are two plots side by side in the series of experiments on permanent grass land, each of which received during six consecutive years precisely the same amount of a mixed mineral manure, including potass, and the same amount of nitrogen in the form of ammonia salts. After those six years, one of the two plots was still manured in exactly the same way each year; whilst the other was so, with one exception—namely, the potass was now excluded from the manure. Calculation shows that there was a great excess of potass applied during the first six years; and there was no marked diminution of produce during the five or six years succeeding the cessation of the application. But each year subsequently, up to the present time, now a period of fourteen years, or of nineteen since the exclusion of the potass, the falling off in produce has been very great.

The point of special interest is, however, that all but identically the same amount of nitrogen has been taken up by the herbage growing with the deficiency of potass as by that with the continued supply of it. The colour of the vegetation with the deficiency of potass has been very much darker green than that with the full supply of it. Nevertheless, taking the average of the eight years succeeding the first six of the exclusion of the potass, there has been nearly 400 lbs. less carbon assimilated per acre per annum; and in some of the still later years the deficiency has been very much greater than this.

We have here, then, the significant fact that an equal amount of nitrogen was taken up in both cases, that chlorophyll was abundantly produced, but that the full amount of carbon was not assimilated. In other words, the nitrogen was there, the chlorophyll was there, there was the same sunlight for both plots; but the assimilation-work was not done where there was not a due supply of potass.

Again, in the field in which barley has now been grown for twenty-nine years in succession, there are two plots which have annually received the same amount of nitrogen—the one in conjunction with salts of potass, soda, and magnesia; and the other with the same, and superphosphate of lime in addition. The plot without the superphosphate of lime always maintains a darker green colour. At any given period of growth the dry substance of the produce would undoubtedly contain a higher percentage of nitrogen; but there has been a deficient assimilation of carbon amounting to more than 500 lbs. per acre per annum, over a period of twenty-eight years. Here again, then, the nitrogen was there, the chlorophyll was there, the sunlight was there, but the work was not done.

It may be stated generally that, in comparable cases, depth of green colour, if not beyond a certain limit, may be taken to indicate corresponding activity of carbon assimilation; but the two instances cited are sufficient to show that we may, so far as the nitrogen, the chlorophyll, and the light are concerned, have the necessary conditions for full assimilation, but not corresponding actual assimilation.

It cannot, I think, fail to be recognised that in these considerations we have opened up to view a very wide field of research, and some of the points involved we may hope will receive elucidation from the further prosecution of Dr. Siemens' experiments. He will himself, I am sure, be the first to admit that what he has already accomplished has done more in raising than in settling important questions. I understand that he proposes to submit plants to the action of the separated rays of his artificial light, and the results obtained cannot fail to be of much interest. But it is obvious that the investigation should now pass from its present initiative *character to* that of a strictly quantitative enquiry. We ought to know not only *that, under given* conditions as to light, plants acquire a deeper green colour and *attain maturity* much earlier than under others, but how much matter is which

lated in each case, and something also of the comparative chemical characters of the products. As between the action of one description of light and another, and as between the greater or less continuity of exposure, we ought to be able to form a judgment whether the proper balance between assimilation on the one hand, and growth and proper maturation on the other, has been attained; whether the plants have taken up nitrogen and mineral matter, and produced chlorophyll, in a greater degree than the quantity and the quality of the light have been able to turn to account; or whether the conditions as to light have been such that the processes of transformation and growth from the reserve material provided by assimilation have not been normal, or have not kept pace with the production of that material.

But one word more in reference to Dr. Siemens's results and proposed extension of his enquiries. Even supposing that by submitting growing crops to continuous light by the aid of the electric light during the night, they could be brought to maturity within a period shorter than at present approximately in proportion to the increased number of hours of exposure, the estimates of the cost of illuminating the vegetation of an acre of land certainly do not seem to hold out any hope that agriculture is likely to derive benefit from such an application of science to its needs. If, however, the characters of growth and of maturation should prove to be suitable for the requirements of horticultural products of luxury and high value, it may possibly be otherwise with such productions.

The above considerations obviously suggest the question: What is the office of chlorophyll in the processes of vegetation? Is it, as has generally been assumed, confined to effecting, in some way not yet clearly understood, carbon assimilation, and, this done, its function ended? Or is it, as Pringsheim has recently suggested, chiefly of avail in protecting the subjacent cells and their contents from those rays of light which would be adverse to the secondary processes which have been distinguished as growth?

Appropriate as it would seem that I should attempt to lay before you a *résumé* of results bearing upon the points herein involved, so numerous and so varied have been the investigations which have been undertaken on the several branches of the question in recent years, that adequately to discuss them would occupy the whole time and space at my disposal. I must therefore be content thus to direct attention to the subject and pass on to other points.

It has been shown that the plant may receive abundance of nitrogen, may produce abundance of chlorophyll, and may be subject to the influence of sufficient light, and yet not assimilate a due amount of carbon. On the other hand, it has been seen that the mineral constituents may be liberally provided, and yet, in the absence of a sufficient supply of nitrogen in an available condition, the deficiency in the assimilation of carbon will be still greater. In fact, assuming all the other necessary conditions to be provided, it was seen that the amount of carbon assimilated depended on the available supply of nitrogen.

In a certain general sense it may be said that the success of the cultivator may be measured by the amount of carbon he succeeds in accumulating in his crops. And as, other conditions being provided, the amount of carbon assimilated depends on the supply of nitrogen in an available form within the reach of the plants, it is obvious that the question of the sources of the nitrogen of vegetation is one of first importance. Are they the same for all descriptions of plants? Are they to be sought entirely in the soil, or entirely in the atmosphere, or partly in the one and partly in the other?

These are questions which Mr. Lawes and myself have discussed so frequently that it might seem some apology was due for recurring to the subject here, especially as I referred to it in some of its aspects before this Section at the Sheffield Meeting last year. But the subject still remains one of first importance to agriculture, and it could not be omitted from consideration in such a review as I have undertaken to give. Moreover, there are some points connected with it still unsettled, and some still disputed.

It will be remembered that De Saussure's conclusion was that plants did not assimilate the free or uncombined nitrogen of the atmosphere, and that they

derived their nitrogen from the compounds of it existing in the atmosphere, and especially in the soil. Liebig, too, concluded that plants do not assimilate nitrogen from the store of it existing in the free or uncombined state, but that ammonia was their main source, and he assumed the amount of it annually coming down in rain to be much more than we now know to be the case.

Referring to our previous papers for full details respecting most of the points in question, I will state, as briefly as I can, the main facts known—first in regard to the amount of the measurable, or as yet measured, annual deposition of combined nitrogen from the atmosphere; and secondly as to the amount of nitrogen annually assimilated over a given area by different crops—so that some judgment may be formed as to whether the measured atmospheric sources are sufficient for the requirements of agricultural production, or whether, or where, we must look for other supplies?

First, as to the amount of combined nitrogen coming down as ammonia and nitric acid in the measured aqueous deposits from the atmosphere.

Judging from the results of determinations made many years ago, partly by Mr. Way, and partly by ourselves, in the rain, &c., collected at Rothamsted; from the results of numerous determinations made much more recently by Professor Frankland in the deposits collected at Rothamsted, and also in rain collected elsewhere; from the results obtained by Boussingault in Alsace; from those of Marié-Davy at the Meteorological Observatory at Montsouris, Paris; and from those of many others made in France and Germany we concluded, some years ago, that the amount of combined nitrogen annually so coming down from the atmosphere would not exceed 8 or 10 lbs. per acre per annum in the open country in Western Europe. Subsequent records would lead to the conclusion that this estimate is more probably too high than too low. And here it may be mentioned in passing, that numerous determinations of the nitric acid in the drainage water collected from land at Rothamsted, which had been many years unmanured, indicate that there may be a considerable annual loss by the soil in that way; indeed, probably sometimes much more than the amount estimated to be annually available from the measured aqueous deposits from the atmosphere.

It should be observed, however, that the amount of combined nitrogen, especially of ammonia, is very much greater in a given volume of the minor aqueous deposits than it is in rain; and there can be no doubt that there would be more deposited within the pores of a given area of soil than on an equal area of the non-porous even surface of a rain-gauge. How much, however, might thus be available beyond that determined in the collected and measured aqueous deposits, the existing evidence does not afford the means of estimating with any certainty.

The next point to consider is—What is the amount of nitrogen annually obtained over a given area, in different crops, when they are grown without any supply of it in manure? The field experiments at Rothamsted supply important data relating to this subject.

Thus, over a period of 32 years (up to 1875 inclusive), wheat yielded an average of 20·7 lbs. of nitrogen per acre per annum, without any manure; but the annual yield has declined from an average of more than 25 lbs. over the first 8, to less than 16 lbs. over the last 12, of those 32 years; and the yield (it is true with several bad seasons), has been still less since.

Over a period of 24 years, barley yielded 18·3 lbs. of nitrogen per acre per annum, without any manure; with a decline from 22 lbs. over the first 12, to only 14·6 lbs. over the next 12 years.

With neither wheat nor barley did a complex mineral manure at all materially increase the yield of nitrogen in the crops.

A succession of so-called 'root crops'—common turnips, Swedish turnips, and sugar beet (with 3 years of barley intervening after the first 8 years)—yielded, with a complex mineral manure, an average of 26·8 lbs. of nitrogen per acre per annum over a period of 31 years. The yield declined from an average of 42 lbs. over the first 8 years, to only 13·1 lbs. (in sugar beet) over the last 5 of the 31 years; but it has risen somewhat during the subsequent 4 years, with a change of crop to mangolds.

With the leguminous crop, beans, there was obtained, over a period of 24 years, 31·3 lbs. of nitrogen per acre per annum without any manure, and 45·5 lbs. with a complex mineral manure, including potass (but without nitrogen). Without manure the yield declined from 48·1 lbs. over the first 12 years to only 14·6 lbs. over the last 12; and with the complex mineral manure it declined from 61·5 lbs. over the first 12, to 29·5 lbs. over the last 12, years of the 24.

Again, an ordinary rotation of crops—of turnips, barley, clover or beans, and wheat—gave over a period of 28 years an average of 36·8 lbs. of nitrogen per acre per annum without any manure, and of 45·2 lbs. with superphosphate of lime alone, applied once every four years, that is for the root crop. Both without manure, and with superphosphate of lime alone, there was a considerable decline in the later courses.

A very remarkable instance of nitrogen yield is the following—in which the results obtained when barley succeeds barley, that is when one gramineous crop succeeds another, are contrasted with those when a leguminous crop, clover, intervenes between the two cereal crops. Thus, after the growth of six grain crops in succession by artificial manures alone, the field so treated was divided, and, in 1873, on one half barley, and on the other half clover, was grown. The barley yielded 37·3 lbs. of nitrogen per acre, but the three cuttings of clover yielded 151·3 lbs. In the next year, 1874, barley succeeded on both the barley and the clover portions of the field. Where barley had previously been grown, and had yielded 37·3 lbs. of nitrogen per acre, it now yielded 39·1 lbs.; but where the clover had previously been grown, and had yielded 151·3 lbs. of nitrogen, the barley succeeding it gave 69·4 lbs., or 30·3 lbs. more after the removal of 151·3 lbs. in clover, than after the removal of only 37·3 lbs. in barley.

Nor was this curious result in any way accidental. It is quite consistent with agricultural experience that the growth and removal of a highly nitrogenous leguminous crop should leave the land in high condition for the growth of a gramineous corn crop, which characteristically requires nitrogenous manuring; and the determinations of nitrogen in numerous samples of the soil taken from the two separate portions of the field, after the removal of the barley, and the clover, respectively, concurred in showing considerably more nitrogen, especially in the first 9 inches of depth, in the samples from the portion where the clover had been grown, than in those from the portion whence the barley had been taken. Here, then, the surface soil, at any rate, had been considerably enriched in nitrogen by the growth and removal of a very highly nitrogenous crop.

Lastly, clover has now been grown for twenty-seven years in succession, on a small plot of garden ground which had been under ordinary garden cultivation for probably two or three centuries. In the fourth year after the commencement of the experiment, the soil was found to contain, in its upper layers, about four times as much nitrogen as the farm-arable-land surrounding it; and it would doubtless be correspondingly rich in other constituents. It is estimated that an amount of nitrogen has been removed in the clover crops grown, corresponding to an average of not far short of two hundred pounds per acre per annum; or about ten times as much as in the cereal crops, and several times as much as in any of the other crops, growing on ordinary arable land; and, although the yield continues to be very large, there has been a marked decline over the second half of the period compared with the first. Of course, calculations of the produce of a few square yards into quantities per acre can only be approximately correct. But there can at any rate be no doubt whatever that the amount of nitrogen annually removed has been very great; and very far beyond what it would be possible to attain on ordinary arable land; where, indeed, we have not succeeded in getting even a moderate growth of clover for more than a very few years in succession.

One other illustration should be given of the amounts of nitrogen removed from a given area of land by different descriptions of crop, namely, of the results obtained when plants of the gramineous, the leguminous, and other families, are growing together, as in the mixed herbage of grass-land.

It is necessary here to remind you that gramineous crops grown separately on arable land, such as wheat, barley, or oats, contain a comparatively small percentage

of nitrogen, and assimilate a comparatively small amount of it over a given area. Yet, nitrogenous manures have generally a very striking effect in increasing the growth of such crops. The highly nitrogenous leguminous crops (such as beans and clover), on the other hand, yield, as has been seen, very much more nitrogen over a given area, and yet they are by no means characteristically benefited by direct nitrogenous manuring; whilst, as has been shown, their growth is considerably increased, and they yield considerably more nitrogen over a given area, under the influence of purely mineral manures, and especially of potass manures. Bearing these facts in mind, the following results, obtained on the mixed herbage of grass land, will be seen to be quite consistent.

A plot of such mixed herbage, left entirely unmanured, gave over twenty years an average of 33 pounds of nitrogen per acre per annum. Over the same period another plot, which received annually a complex mineral manure, including potass, during the first six years, but excluding it during the last fourteen years, yielded 46·3 lbs. of nitrogen; whilst another, which received the mixed mineral manure, including potass, every year of the twenty, yielded 55·6 lbs. of nitrogen per acre per annum. Without manure, there was some decline of yield in the later years; with the partial mineral manuring there was a greater decline; but with the complete mineral manuring throughout the whole period, there was even some increase in the yield of nitrogen in the later years.

Now, the herbage growing without manure comprised about fifty species, representing about twenty natural families; that growing with the limited supply of potass comprised fewer species, but a larger amount of the produce, especially in the earlier years, consisted of leguminous species, and the yield of nitrogen was greater. Lastly, the plot receiving potass every year yielded still more leguminous herbage, and, accordingly, still more nitrogen.

The most striking points brought out by the foregoing illustrations are the following:—

First. Without nitrogenous manure, the gramineous crops annually yielded, for many years in succession, much more nitrogen over a given area than is accounted for by the amount of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere.

Second. The root crops yielded more nitrogen than the cereal crops, and the leguminous crops very much more still.

Third. In all cases—whether of cereal crops, root crops, leguminous crops, or a rotation of crops—*the decline in the annual yield of nitrogen, when none was supplied, was very great.*

How are these results to be explained? Whence comes the nitrogen? and especially whence comes the much larger amount taken up by plants of the leguminous and some other families, than by the gramineæ? And, lastly, what is the significance of the great decline in the yield of nitrogen in all the crops when none is supplied in the manure?

Many explanations have been offered. It has been assumed that the combined nitrogen annually coming down from the atmosphere is very much larger than we have estimated it, and that it is sufficient for all the requirements of annual growth. It has been supposed that 'broad-leaved plants' have the power of taking up nitrogen in some form from the atmosphere, in a degree, or in a manner, not possessed by the narrow-leaved gramineæ. It has been argued that, in the last stages of the decomposition of organic matter in the soil, hydrogen is evolved, and that this nascent hydrogen combines with the free nitrogen of the atmosphere, and so forms ammonia. It has been suggested that ozone may be evolved in the oxidation of organic matter in the soil, and that, uniting with free nitrogen, nitric acid would be produced. Lastly, it has by some been concluded that plants assimilate the free nitrogen of the atmosphere, and that some descriptions are able to do this in a greater degree than others.

We have discussed these various points on more than one occasion; and we have given our reasons for concluding that none of the explanations enumerated can be taken as accounting for the facts of growth.

Confining attention here to the question of the assimilation of free nitrogen

lants, it is obvious that, if this were established, most of our difficulties would anish. This question has been the subject of a great deal of experimental enuiry, from the time that Boussingault entered upon it, about the year 1837, nearly p to the present time. About twenty years ago it was elaborately investigated at lothamsted. In publishing the results of that inquiry, those of others relating o it were fully discussed; and although the recorded evidence is admittedly very onflicting, we then came to the conclusion, and still adhere to it, that the balance f the direct experimental evidence on the point is decidedly against the supposition of the assimilation of free nitrogen by plants. Indeed, the strongest rgument we know of in its favour, is, that some such explanation is wanted.

Not only is the balance of direct experimental evidence against the assumpion that plants assimilate free or uncombined nitrogen, but it seems to us that he balance of existing indirect evidence is also in favour of another explanation f our difficulties.

I have asked what is the significance of the gradual decline of produce of all he different crops when continuously grown without nitrogenous manure? It annot be that, in growing the same crop year after year on the same land, there s any residue left in the soil that is injurious to the subsequent growth of the same lescription of crop; for (excepting the beans) more of each description of crop has een grown year after year on the same land than the average yield of the country t large under ordinary rotation, and ordinary treatment—provided only, that uitable soil-conditions were supplied. Nor can the diminishing produce, and the liminishing yield of nitrogen, be accounted for on the supposition that there was a leficient supply of available mineral constituents in the soil. For, it has been hown that the cereals yielded little more, and declined nearly as much as withut manure, when a complex mineral manure was used, such as was proved to be dequate when available nitrogen was also supplied. So far as the root crops are oncerned, the yield of nitrogen, though it declined very much, was greater at first, nd on the average, than in the case of the cereals. As to the leguminosæ, which equire so much nitrogen from somewhere, it is to be observed that on ordinary rable land the yield has not been maintained under any conditions of manuring; nd the decline was nearly as marked with mineral manures as without any nanure. Compared with the growth of the leguminosæ on arable land, the emarkable result with the garden clover would seem clearly to indicate that the uestion was one of soil, and not of atmospheric supply. And the fact that all he other crops will yield full agricultural results even on ordinary arable land, when proper manures are applied, is surely very strong evidence that it is with hem, too, a question of soil, and not of atmospheric supply.

But we have other evidence leading to the same conclusion. Unfortunately re have not reliable samples of the soil of the different experimental fields taken t the commencement of each series of experiments, and subsequently at stated ntervals. We have, nevertheless, in some cases, evidence sufficient to show whether or not the nitrogen of the soil has suffered diminution by the continuous rowth of the crop without nitrogenous manure.

Thus, we have determined the nitrogen in the soil of the continuously unmanured wheat plot at several successive periods, and the results prove that a gradual eduction in the nitrogen of the soil is going on; and, so far as we are able to form a udgment on the point, the diminution is approximately equal to the nitrogen taken ut in crops; and the amount estimated to be received in the annual rainfall is approximately balanced by the amount lost by the land as nitrates in the drainage water.

In the case of the continuous root-crop soil, on which the decline in the yield f nitrogen in the crop was so marked, the percentage of nitrogen, after the xperiment had been continued for twenty-seven years, was found to be lower where no nitrogen had been applied than in any other arable land on the farm which has been examined.

In the case of the experiments on the mixed herbage of grass land, the soil of he plot which, under the influence of a mixed mineral manure, including otass, had yielded *such a large* amount of leguminous herbage, and such a large mount *of nitrogen, showed, after* twenty years, a considerably lower percent e *of nitrogen than that of* any other plot in the series.

Lastly, determinations of nitrogen in the garden soil which has yielded so much nitrogen in clover, made in samples collected in the fourth and the twenty-sixth years of the twenty-seven of the experiments, show a very large diminution in the percentage of nitrogen. The diminution, to the depth of 9 inches only, represents approximately three-fourths as much as the amount estimated to be taken out in the clover during the intervening period; and the indication is, that there has been a considerable reduction in the lower depths also. It is to be supposed, however, that there would be loss in other ways than by the crop alone.

I would ask, Have we not in these facts—that full amounts of the different crops can be grown, provided proper soil-conditions are supplied; that without nitrogenous manure the yield of nitrogen in the crop rapidly declines; and that, coincidently with this, there is a decline in the percentage of nitrogen in the soil—have we not in these facts, cumulative evidence pointing to the soil, rather than to the atmosphere, as the source of the nitrogen of our crops?

In reference to this point, I may mention that the ordinary arable soil at Rothamsted may be estimated to contain about 3,000 lbs. of nitrogen per acre in the first 9 inches of depth, about 1,700 lbs. in the second 9 inches, and about 1,500 lbs. in the third 9 inches—or a total of about 6,200 lbs. per acre to the depth of 27 inches.

In this connection, it is of interest to state that a sample of Oxford clay, obtained in the sub-Wealden exploration boring, at a depth of between 500 and 600 feet (and which was kindly given to me by the President of the Association, Professor Ramsay, some years ago), showed, on analysis at Rothamsted, approximately the same percentage of nitrogen as the subsoil at Rothamsted taken to the depth of about 4 feet only.

Lastly, in a letter received from Boussingault some years ago, referring to the sources whence the nitrogen of vegetation is derived, he says:—

'From the atmosphere, because it furnishes ammonia in the form of carbonate, nitrates, or nitrites, and various kinds of dust. Theodore de Saussure was the first to demonstrate the presence of ammonia in the air, and consequently in meteoric waters. Liebig exaggerated the influence of this ammonia on vegetation, since he went so far as to deny the utility of the nitrogen which forms a part of farm-yard manure. This influence is nevertheless real, and comprised within limits which have quite recently been indicated in the remarkable investigations of M. Schlösing.

'From the soil, which, besides furnishing the crops with mineral alkaline substances, provides them with nitrogen, by ammonia, and by nitrates, which are formed in the soil at the expense of the nitrogenous matters contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilising by the effect of time. If we take into account their immensity, the deposits of the last geological periods must be considered as an inexhaustible reserve of fertilising agents. Forests, prairies, and some vineyards, have really no other manures than what are furnished by the atmosphere and by the soil. Since the basis of all cultivated land contains materials capable of giving rise to nitrogenous combinations, and to mineral substances, assimilable by plants, it is not necessary to suppose that in a system of cultivation the excess of nitrogen found in the crops is derived from the free nitrogen of the atmosphere. As for the absorption of the gaseous nitrogen of the air by vegetable earth, I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off, as you have observed in conjunction with Mr. Lawes, as Reiset has shown in the case of dung, as M. Schlösing and I have proved in our researches on nitrification.

'If there is one fact perfectly demonstrated in physiology, it is this of the non-assimilation of free nitrogen by plants; and I may add by plants of an inferior order, such as mycoderms and mushrooms. (Translation).'

If, then, our soils are subject to a continual loss of nitrogen by drainage, probably in many cases more than the receive of combined nitrogen from the atmosphere—if the nitrogen of our crops is derived mainly from the soil, and not from the atmosphere—and if, when due return is not made from without, we see

rawing upon what may be termed the store of nitrogen of the soil itself—is there not, in the case of many soils at any rate, as much danger of the exhaustion of their available nitrogen, as there has been supposed to be of the exhaustion of their available mineral constituents?

I had hoped to say something more about soils, to advance our knowledge respecting which an immense amount of investigation has been devoted of late years, but in regard to which we have yet very much more to learn. I must, however, now turn to other matters.

I have thus far directed attention to some points of importance in connection with the sources of the constituents of our crops, and I must now briefly refer to some in connection with the composition, and to some relating to the uses, of the crops themselves.

As to composition, I must confine myself to indicating something of what is known of the condition of the nitrogen in our various crops; though I had intended to say something respecting the carbo-hydrates, and especially respecting the various members of the cellulose group.

As to the nitrogen—in our first experiments on the feeding of animals, made in 1847, 1848, and 1849, the results of which were published in the last-mentioned year—we found that, in the case of succulent roots used as food, not only were they not of value as food in proportion to their richness in nitrogen, but when the percentage of it was higher than a certain normal amount, indicating relative succulence and immaturity, they were positively injurious to the animals. So marked was the variation of result according to the condition of maturity or otherwise of the foods employed, that, when reviewing the results of the experiments which had up to that time been conducted, in a paper read before this Section of the British Association at the Belfast Meeting in 1852 (and which was published in full in the annual volume[1]), we stated that the mode of estimating the amount of proteine compounds by multiplying the percentage of nitrogen by 6·3 was far from accurate, especially when applied to succulent vegetable foods, and that the individual compounds ought to be determined. The Rothamsted Laboratory staff was, however, much smaller then than it is now, and with the pressure of many other subjects upon us, it was at that time quite impossible to follow up the enquiry in that direction.

It is, indeed, only within the last ten years or so, that the question has been taken up at all systematically; but we are already indebted to E. Schulze, A. Frick, Church, Sachsse, Maercker, Kellner, Vines, Emmerling, and others, for important results relating to it.

Our knowledge in regard to the subject is, however, still very imperfect. But it is in progress of investigation from two distinctly different points of view—from that of the vegetable physiologist, and that of the agricultural chemist. The vegetable physiologist seeks to trace the changes that occur in the germination of the seed, and during the subsequent life-history of the plant, to the production of seed again. The agricultural chemist takes the various vegetable products in the condition in which they are used on the farm, or sold from it. And, as a very large proportion of what is grown, such as grass, hay, roots, tubers, and various green crops, are not matured productions, it comes to be a matter of great importance to consider whether or not any large proportion of the nitrogenous contents of such products is in such condition as not to be of avail to the animals which consume them in their food?

We cannot say that the whole of the nitrogen in the seeds with which we have to deal exists as albuminoids. But we may safely assume that the nearer they approach to perfect ripeness, the less of non-albuminoid nitrogenous matters will they contain; and, in the case of the cereal grains at any rate, it is probable that if really perfectly ripe they will contain very nearly the whole of their nitrogen as albuminoids. With regard to some leguminous and other seeds, which contain peculiar nitrogenous bodies, the range may, however, be wider.

[1] 'On the Composition of Foods, in relation to Respiration and the Feeding of Animals.'

But whatever the condition of the nitrogenous bodies in the seeds we sow, with germination begins a material change. Albuminoids are tran into peptones, or peptone-like bodies, or degraded into various amido compounds. Such change into more soluble and more diffusible bodies i be supposed, essential to their free migration, and to their subservienc purposes of growth. In the case of the germination, especially of some nous seeds, asparagine has been found to be a very prominent pr such degradation of the albuminoids ; but it would seem that this disap the green parts are developed. But now the plant begins to receive su nitrogen from the soil, as nitrates or ammonia, and it would seem tha constitute a considerable proportion of the produced nitrogenous bodi rently as an intermediate stage in the formation of albuminoids. At a such bodies are found to exist largely in the immature plant ; whilst th of them diminishes as the plant, or its various parts, approach to maturi

But not only have we thus, in unripened vegetable productions, a g less, and sometimes a very large, proportion of the nitrogenous bodie within the plant, existing as amido-compounds, but we may have a larg existing in the juices as nitric acid, and some as ammonia, &c. Thus, E determined the nitric acid in various 'roots'; and he found that, mangels, more than one-third of the total nitrogen existed in that f about one-tenth as much as ammonia. In a considerable series at Rot we have found an extremely variable proportion existing as nitric acid, a to the size, succulence, or degree of maturity, of the roots ; the amount a rule, the least with the ripest and less highly nitrogenous roots, and with the most succulent, unripe, and highly nitrogenous ones. In s it reached as much as from 20 to nearly 30 per cent. of the total nitro many other immature vegetable products nitric acid and ammonia h found ; but, so far as I remember, in none in anything like so large a p as in the so-called 'root-crops,' especially mangels. In many, how quantity appears to be immaterial ; and it is remarkable that whilst th much in the 'roots,' little or none is found in potatoes.

No wonder that, in the experiments already referred to, we found th result to be the worse the more succulent and immature the roots, and t their percentage of nitrogen, accordingly.

But it is to the difference in amount of the albuminoid bodies them different descriptions of vegetable produce, that I wish specially to dir tion, making, however, some reference to what is known of the proport nitrogen existing as amido-compounds.

In some mangels E. Schulze found only from about 20 to 22 per cen total nitrogen to exist as insoluble and soluble albumin. But he fou case 32·5, and in the other 40·8 per cent. of the total nitrogen as amid large series of determinations at Rothamsted, by Church's method, w variation of from under 20 to over 40 per cent. of the total nitrogen o to exist as albuminoids ; or, in other words, from nearly 60 to over 80 of it in the non-albuminoid condition.

In potatoes Schulze found from under 50 to 65 per cent. of the total as soluble and insoluble albumin, and from 27·7 to 49·1 per cent. as n acid amides. In a series of potatoes grown at Rothamsted, under ver conditions as to manuring, and in two different seasons, we found the as albuminoids to range from little over 50 to more than 71 per cent. o nitrogen : leaving, of course, from less than 30 to nearly 50 per c accounted for in other ways.

Kellner determined the amount of nitrogen as albuminoids, and as am pounds, in a considerable series of green foods, both leguminous and gr cut at different stages of their growth. The proportion of the total nitro albuminoids was, upon the whole, greater in the leguminosæ than in the g *In both, however, the proportion as albuminoids increased as the plants a to maturity.* The proportion as albuminoids was in all these products *larger than in roots*, and generally larger than in potatoes. In the case

neadow hay, we found in the separated gramineous herbage 76·4, in the leguminous erbage 82, and in the miscellaneous herbage 80·3 per cent. of the nitrogen as lbuminoids; and in the second crop 86·2 per cent. in the gramineous, 88·3 per ent. in the leguminous, and 88·1 per cent. in the miscellaneous herbage. How far he higher proportion of the nitrogen as albuminoids in the second crops is to be aken as any indication of the characteristics of the autumn growth, or how far it s to be attributed to the accidental condition of the weather, may be a question.

These illustrations are sufficient to give some idea of the range and proportion f the nitrogen in different feeding crops which does not exist as albuminoids; and hey are sufficient to show that a very large proportion of the non-albuminoid natter exists as various amido-compounds. The question arises, therefore, whether hese bodies contribute in any way to the nutrition of the animals which feed upon hem? We have but little experimental evidence on this point. As green herbage s the natural food of many descriptions of animal, we might suppose that characeristic constituents of it would not be without some value as food; but the cultiated root crops are much more artificial productions, and it is in them that we ind such a very large proportion of non-albuminoid nitrogen. With respect to ome of the amido-compounds, at any rate, direct experiments seem to show that hey are digested in the animal body, and increase the elimination of urea. Weiske nd Schrodt found that rabbits receiving, as their only nitrogenous food, either sparagine or gelatin, wasted and died; but a rabbit receiving both asparagine and elatin increased in weight and survived to the end of the experiment, which asted seventy-two days. From the results of other experiments made with heep, they concluded that both asparagine and gelatin protect the albuminoids f the body from oxidation.

These considerations lead me, in conclusion, to refer briefly, and I promise it hall be as briefly as is consistent with clearness, to the two very much disputed uestions of *the origin of muscular power*, and *the sources of the fat of the animal ody*. These subjects Mr. Lawes and myself have frequently discussed elsewhere; ut as the controversy has assumed a new phase quite recently, it seems desirable nd appropriate that I should recur to it on the present occasion.

With regard to the question of the sources in the food of the fat of the nimal body, Liebig originally maintained that although fat might be formed rom the nitrogenous compounds within the body, the main source of it in the erbivora was the carbo-hydrates. In his later writings, he sharply criticised he experiments and arguments of those who have maintained the formation of t chiefly from the proteine compounds; but he at the same time seems to attach nore importance to that source than he formerly did. He gives it as his opinion hat the question cannot be settled by experiments with herbivora. He adds hat what we know with certainty is that, with these animals, albuminates and arbo-hydrates work together to produce fat; but whether the non-nitrogenous roduct, fat, has its origin in the albumin or in the carbo-hydrate, he considers not easy to determine.

At the time when we commenced our experiments on the feeding of animals 1847, the question whether the fat of the animals fed for human food was ainly derived from albuminoids or from carbo-hydrates had been scarcely ised, or at least it was not prominent. The question then was rather—whether e herbivora received their fat ready formed in their food, or whether it was oduced within the body—the latter view being that which Liebig had so rcibly urged, at the same time maintaining that at any rate its chief source was e carbo-hydrates. Accordingly, our experiments were not specially arranged determine whether or not the whole of the fat produced could or could not be rived from the albuminoids.

For each description of animal, oxen, sheep, and pigs, such foods as had been tablished by common experience to be appropriate were selected. The general an of the experiments was—to give to one set a fixed amount of a recognised ood food, containing known quantities of nitrogen, fatty matter, &c.; to other set the *same amount of* another food, of different characters in these pects; *to other sets also* fixed amounts of other foods in the same way; and *there was given*, *to* the whole series, the same complementary food *ad libitum*

Or, to one set was supplied a uniform food rich in nitrogen, and to ot form foods poorer in nitrogen, and so on, in each case *ad libitum.*

It will be seen that, in this way, a great variety of dietaries was arrang it will be observed that in each case the animals themselves fixed their c tion, according to the requirements of the system.

As already indicated, the individual nitrogenous and non-nitrogenous co of the foods were not determined. As a rule, the constituents determi —the total dry matter, the ash, the fatty matter, and the nitrogen: fr last the amount of nitrogenous compounds it might represent was calculat usual factor. But, as already intimated, the results so obtained were only considerable reservation, especially in the case of all immature vegetable Nor was the crude fibre determined; but, as in the case of the estimat genous substance, when interpreting the results, it was always considere or not the food contained much or little of probably indigestible woody

The animals being periodically weighed, we were thus able to calc amounts of the so-estimated nitrogenous substance, and of the total n genous substance, including and excluding fat, consumed—*for a given l within a given time*, and *to produce a given amount of increase in live-weig*

Experiments were made with a large number of sheep, and a large r pigs. And, even without making allowance for the different condition of genous or of the non-nitrogenous constituents, in comparable foods, the r tained uniformly indicated that both the amount consumed by a given li of animal within a given time, and that required to produce a given a increase, were determined much more by the amount of the non-nitrogenou that of the nitrogenous constituents which the food supplied. And when was made for the different condition of the nitrogenous constituents, a greater or less amount of the non-nitrogenous ones which would probabl gestible and effete, the indications were still more remarkable and concl

In very many cases the animals were slaughtered, and carefully exami whether the tendency of development had been more that of growth and flesh, or in fatness. Here, again, the evidence was clear—that the to growth in frame and flesh was favoured by a high proportion of ni the food, and that to the production of fat by a high proportion of non-nitrogenous constituents.

In a few cases the actual amount of fat in the animals in the lean, fat condition, was determined; and the results admitted of no doubt that a very large proportion of the stored-up fat could not have been de the fatty matter of the food, and must have been produced within the

So decisive and consistent were the very numerous and very varied regard to these points, that we had no hesitation in concluding—not much of the fat stored up was produced within the body, but that the much, at any rate, of the produced fat must have been the non-ni constituents of the food—in other words, the *carbo-hydrates.*

As already stated, however, as the question whether the source of duced fat was the proteine compounds or the carbo-hydrates was prominent, we had not so arranged the experiments as to obtain t possible increase in fat with the smallest possible supply of nitrogenous c in the food; nor did we then even calculate whether or not there was nitrogenous matter consumed to be the source of the whole of the fat

This question, indeed, excited very little interest, until, at a meeti Congress of Agricultural Chemists held at Munich in 1865 (at which I to be present), Professor Voit, from the results of experiments Pettenkofer's respiration apparatus with dogs fed on flesh, announced sion that fat must have been produced from the nitrogenous substance this was probably the chief, if not the only, source of the fat, even of —an opinion which he subsequently urged much more positively.

In the discussion which followed the reading of Professor Vo *Baron Liebig forcibly* called in question his conclusions; maintaining *it was inadmissible* to form conclusions on such a point in regard to

from the results of experiments made with carnivora, but also that direct quantitative results obtained with herbivorous animals had afforded apparently conclusive evidence in favour of the opposite view.

Voit's paper excited considerable controversy, in which Mr. Lawes and myself joined. We maintained that experiments to determine such a question should be made, not with carnivora or omnivora fed on flesh, but with herbivora fed on their appropriate fattening food, and on such herbivora as common experience showed to be pre-eminently fat-producers. We pointed out[1] that the pig comprised, for a given live-weight, a comparatively small proportion of alimentary organs and contents; that, compared with that of the ruminants, his food was of a high character, yielding, for a given weight of it, much more total increase, much more fat, and much less necessarily effete matter; that, in proportion to his weight, he consumes a larger amount of food, and yields a larger amount, both of total increase and of fat, within a given time; and, lastly, that he contains a larger proportion of fat, both in a given live weight, and in his increase whilst fattening.

It is obvious that, with these characteristics, there is much less probable range of error in calculating the amount and the composition of the increase in live-weight in relation to the amount and composition of the food consumed, than in the case of the ruminants; and that, therefore, the pig is very much more appropriate for the purpose of experiments to determine the sources in its food of the fat it produces.

Accordingly, we calculated a number of our early experiments made with pigs, to determine whether or not the nitrogenous substance they consumed was sufficient for the formation of the fat they produced. For simplicity of illustration, and to give every possible advantage to the view that nitrogenous substance might have been the source of the produced fat, we assumed the whole of the crude fat of the food to have been stored up in the animal—thus estimating a minimum amount to be produced. Then, again, we supposed the whole of the nitrogenous substance of the food to be perfectly digested, and to become available for the purposes of the system. Lastly, after deducting the amount of nitrogenous substance estimated to be stored up as such, the whole of the remainder was reckoned to be so broken up that no other carbon-compounds than fat and urea would be produced.

The result was that, even adopting these inadmissible assumptions, in all the cases in which, according to common experience, the food was admittedly the most appropriate for the fattening of the animal, the calculation showed that a large amount of fat had been produced which could not have been derived from the nitrogenous substance of the food, and must, therefore, have had its source in the carbo-hydrates. Such a result is, moreover, entirely accordant with experience in practical feeding.

Reviewing the whole subject in great detail in 1869, Professor Voit refers to these results and calculations. He confesses that he has not been able to get a general view of the experiments from the mass of figures recorded, and from his comments he shows that he has on some points misunderstood them. He admits, however, that, as the figures stand, it would appear that fat had, in some instances, been derived from the carbo-hydrates. Still, he says, he cannot allow himself to consider that a transformation of carbo-hydrates into fat has thus been proved.

Professor Emil von Wolff, again, in his *Landwirthschaftliche Fütterungslehre*, referring to the same experiments, admits that they are almost incomprehensible unless we assume the direct concurrence of the carbo-hydrates in the formation of fat. He, nevertheless, seems to consider that evidence of the kind in question is inconclusive; and he suggests that experiments with pigs should be made in a respiration apparatus to determine the point.

Mr. Lawes and myself entertained, however, the utmost confidence that the question was of easy settlement without any such apparatus, provided only suitable animals and suitable foods were selected. I, accordingly, gave a paper on the subject in the *Section für Landwirthschaft-und Agricultur-Chemie*, at the *Naturforscher Versammlung* held at Hamburg in 1876.[2] The points which I particu-

[1] '*On the Sources of the Fat of the Animal Body*,' *Phil Mag.*, December, 1866.
[2] *The substance of that communication* is given in the *Journal of Anatomy and Physiology*, *vol. xi. part iv.*

larly insisted upon were—that the pig should be the subject of experiment; that he should be allowed to take as much as he would eat of his most appropriate fattening food, so that his increase, and the fat he produced, should bear as large a proportion as possible to his weight, to the total food, and to the total nitrogenous substance consumed. Finally, it was maintained that, if these conditions were observed, and the constituents of the food determined, and those of the increase of the animal estimated according to recognised methods, the results could not fail to be perfectly conclusive, without the intervention, either of a respiration apparatus, or of the analysis of the solid and liquid matters voided.

Results so obtained were adduced in proof of the correctness of the conclusions arrived at. We at the same time admitted that, although, for reasons indicated, we had always assumed that fat was formed from the carbo-hydrates in the case of ruminants as well as of pigs, yet, as in our experiments with those animals we had supplied too large amounts of ready formed fat, or of nitrogenous matter, or of both, it could not be shown so conclusively by the same mode of calculation in their case as in that of pigs.

In the discussion which followed, Professor Henneberg agreed that it seemed probable that fat could be formed from the carbo-hydrates in the case of pigs. In the case of experiments with other animals, however, the amount of fat produced was too nearly balanced by the amount of fat and albuminous matters available, to afford conclusive evidence on the point.

Quite recently, Professor Emil von Wolff (*Landwirthschaftliche Jahrbücher*, Band viii. 1879, Supplement) has applied the same mode of calculation to results obtained by himself with pigs some years ago. He concluded that the whole of the body fat could not have been formed without the direct co-operation of the carbo-hydrates of the food. But what is of greater interest still is, that he also calculated, in the same way, the results of some then quite recent experiments of Henneberg, Kern, and Wattenberg, with sheep. He thus found that, even including the whole of the estimated amides with the albumin, there must have been a considerable production of fat from the carbo-hydrates; and, excluding the amides, the amount reckoned to be derived from the carbo-hydrates was of course much greater.

I will only add, on this point, that, on re-calculating some of our early results with sheep, which did not afford sufficiently conclusive evidence when the whole of the nitrogen of the food was reckoned as albumin, show a very considerable formation of fat from the carbo-hydrates, if deduction be made for the probable amount of non-albuminoid nitrogenous matter of the food.

We have now, then, the two agricultural chemists of perhaps the highest authority, both as experimenters and writers on this subject on the Continent, giving in their adhesion to the view, that the fat of the herbivora, which we feed for human food, may be, and probably is, largely produced from the carbo-hydrates. I dare say, however, that some physiologists will not change their view until Voit gives them sanction by changing his, which, so far as I know, he has not yet done.

The question which has been currently entitled that of '*The Origin of Muscular Power*,' or, '*The Sources of Muscular Power*,' has also been the subject of much investigation, and of much conflict of opinion, since the first publication of Liebig's views respecting it in 1842.

As I have already pointed out, he then maintained that the amount of muscular tissue transformed, the amount of nitrogenous substance oxidated, was the measure of the force generated in the body. He accordingly concluded that the requirement for the nitrogenous constituents of food would be increased in proportion to the increase of the force expended. In his more recent writings on the subject, he freely criticises those who take an opposite view. He nevertheless grants that the secretion of urea is not a measure of the force exerted; but, on the other hand, he does not commit himself to the admission that the oxidation of the carbo-hydrates is a source of muscular power.

The results of our own early and very numerous feeding experiments were, as has been said, extremely accordant in showing that, provided the nitrogenous constituents in the food were not below a certain rather limited amount, it was the quantity of the digestible and available non-nitrogenous constituents, and not that

the nitrogenous substance, that determined—both *the amount consumed by a given* *e-weight within a given time*, and *the amount of increase in live-weight produced.* hey also showed that one animal, or one set of animals, might consume two or ree times as much nitrogenous substance in proportion to a given live-weight ithin a given time as others in precisely comparable conditions as to rest or ercise. It was further proved that they did not store up nitrogenous substance t all in proportion to the greater or less amount of it supplied in the food, but at the excess reappeared in the liquid and solid matters voided.

So striking were these results, that we were led to turn our attention to human ietaries, and also to a consideration of the management of the animal body ndergoing somewhat excessive labour, as, for instance, the hunter, the racer, he cab-horse, and the foxhound, and also pugilists and runners. Stated in a ery few words, the conclusion at which we arrived from these inquiries (which rere summarised in our paper given at Belfast in 1852) was—that, unless the ystem were overtaxed, the demand induced by an increased exercise of force ras more characterised by an increased requirement for the more specially respiatory, than for the nitrogenous, constituents of food.

Soon afterwards, in 1854, we found by direct experiments with two animals n exactly equal conditions as to exercise, both being in fact at rest, that the mount of urea passed by one feeding on highly nitrogenous food was more than wice as great as that fed on a food comparatively poor in nitrogen.

It was clear, therefore, that the rule which had been laid down by Liebig, and which has been assumed to be correct by so many writers, even up to the present ime, did not hold good—namely, that 'The sum of the mechanical effects roduced in two individuals, in the same temperature, is proportional to the mount of nitrogen in their urine; whether the mechanical force has been mployed in voluntary or involuntary motions, whether it has been consumed by he limbs or by the heart and other viscera'—unless, indeed, as has been assumed y some experimenters, there is, with increased nitrogen in the food, an increased mount of mechanical force employed in the 'involuntary motions' sufficient to ccount for the increased amount of urea voided.

The question remained in this condition until 1860, when Bischoff and Voit published the results of a long series of experiments made with a dog. They found that, even when the animal was kept at rest, the amount of urea voided varied closely in proportion to the variation in the amount of nitrogenous substance given in the food—a fact which they explained on the assumption that there must have been a corresponding increase in the force exercised in the conduct of the actions proceeding within the body itself in connection with the disposal of the increased amount of nitrogeneous substance consumed. Subsequently, however, they found that the amount of urea passed by the animal was, with equal conditions as to food, &c., no greater when he was subjected to labour than when at rest; whilst, on the other hand, the carbonic acid evolved was much increased by such exercise. They accordingly somewhat modified their views.

In 1866 appeared a paper by Professors Fick and Wislicenus, giving the results obtained in a mountain ascent. They found that practically the amount of urea voided was scarcely increased by the labour thus undertaken. Professor Frankland gave an account of these experiments in a lecture at the Royal Institution in the same year; and he subsequently followed up the subject by an investigation of the heat developed in the combustion of various articles of food, applying the results in illustration of the phenomena of the exercise of force.

Lastly, Kellner has made some very interesting experiments with a horse at Hohenheim, the results of which were published last year. In one series, the experiment was divided into five periods, the same food being given throughout; but the animal accomplished different distances, and drew different weights, the draught being measured by a horse-dynamometer. The changes in live-weight, the amount of water drunk, the temperature, the amount of matters voided, and their contents in nitrogen, were also determined.

The result was, that *with only moderate* labour there was no marked increase

in the nitrogen eliminated in the urine, but that with excessive labour the animal lost weight and eliminated more nitrogen. Kellner concluded, accordingly, that, under certain circumstances, muscular action can increase the transformation of albumin in the organism in a direct way; but that, nevertheless, in the first line is the oxidation of the non-nitrogenous matters—carbo-hydrates and fat, next comes in requisition the circulation-albumin, and finally the organ-albumin is attacked.

In reference to these conclusions from the most recent experiments relating to the subject, we may wind up this brief historical sketch of the changes of view respecting it, with the following quotation from our own paper published in 1866: [1]—' . . . all the evidence at command tended to show that by an increased exercise of muscular power there was, with increased requirement for respirable material, probably no increased production and voidance of urea, unless, owing to excess of nitrogenous matter in the food, or a deficiency of available non-nitrogenous substance, or diseased action, the nitrogenous constituents of the fluids or solids of the body were drawn upon in an abnormal degree for the supply of respirable material.'

In conclusion, although I fully agree with Voit, Zuntz, Wolff, and others, that there still remains much for both Chemistry and Physiology to settle in connection with these two questions of '*The Sources of the Fat of the Animal Body*' and '*The Origin of Muscular Power*,' yet I think we may congratulate ourselves on the re-establishment of the true faith in regard to them, so far at least as the most important practical points are concerned.

[1] 'Food in its relation to various exigencies of the Animal Body.—*Phil. Mag.* July, 1866.

ON THE

HOME PRODUCE, IMPORTS, CONSUMPTION,

AND

PRICE OF WHEAT,

OVER 27 (OR 28) HARVEST-YEARS,
1852–3 TO 1879–80.

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ON THE

HOME PRODUCE, IMPORTS, CONSUMPTION,

AND

PRICE OF WHEAT,

OVER 27 (OR 28) HARVEST-YEARS, 1852–3 TO 1879–80.

In our paper "On the Home Produce, Imports and Consumption of Wheat," published in the 'Journal' in 1868, we gave records and estimates on the subject for sixteen harvest-years, 1852–3 to 1867–8 inclusive; and in 1863, and each year since, an estimate for the then current year has been published in the 'Times,' and elsewhere, soon after harvest. We propose, on the present occasion, to pass in review the estimates formerly given, and to complete the record from the commencement up to the present time; namely, for twenty-eight (or twenty-seven) years, 1852–3 to 1879–80 inclusive. In our former paper we gave the records and estimates for each division of the United Kingdom separately, and for the whole collectively; but it is proposed now to confine the illustrations to the United Kingdom as a whole.

The main elements of the question are the following:—

1. The area under wheat.
2. The average yield of wheat per acre.
3. The aggregate home produce, and the amount of it available for consumption.
4. The imports.
5. The population.
6. The average consumption of wheat per head of the population per annum.

The data then at command, and the results arrived at, were fully considered in the paper above mentioned, and we must refer to it for detailed information on most of the points in question, but the main facts may be briefly summarised here.

The Area under Wheat.—For the period from 1852 to 18 inclusive, we had to rely on estimates alone in fixing the ar under the crop in England and Wales. For Scotland, we ha Returns collected by the Highland Society for the years 185 1855, 1856, and 1857 ; but for the two years prior to 1854, an for the years subsequent to 1857, down to 1865 inclusive, we ha to rely on estimates merely. For Ireland, Returns were availab for each of the sixteen years included in the inquiry. Than to the exertions of Mr. Caird, we have for 1866, and for ea year since, an official record of the area under the crop, in ea division of the United Kingdom, and in the whole collectivel in the 'Agricultural Returns' now annually published about t time of harvest. One element of uncertainty in any estimates the home produce of wheat is, therefore, fortunately removed.

The Average Yield of Wheat per Acre.—The only Returns official estimates at command relating to this subject, were f Scotland for four years, and for Ireland for each year within t period of our inquiry; whilst, for England and Wales, co prising from 85 to 90 per cent. of the total area under the cro there was, and there is, no official information whatever. F this large proportion of the United Kingdom it was, therefo after very full consideration of the data, and of the results which they led, decided to adopt the average produce per ac each year, on certain selected, and very differently manur plots, in the permanent experimental wheat-field at Rothamste as the basis of estimates of the average produce per acre fro year to year; and, each year since, the same data have be relied upon in forming an estimate of the average produce ov the United Kingdom as a whole. But, having regard to t character of the soil at Rothamsted, to the characters of the in vidual seasons, and to the consideration whether the season w more favourable for heavy or for light land, and so on, t estimate actually adopted for the country at large has, in so seasons, and more especially in bad seasons, differed somewh from the actual average indicated on the selected plots in t experimental field. Lastly, in all cases, the actual number bushels is reduced by calculation, so as to represent bushels the standard weight of 61 lbs. per bushel.

It is proposed, on the present occasion, briefly to examine i the validity of the data thus taken as a basis for estimating t average yield per acre of the country each year, and also into t trustworthiness of the results arrived at, as tested by subsequ knowledge, and by their accordance, or otherwise, with the c clusions arrived at in regard to other elements of the questio

The Aggregate Home Produce, and the Amount of it availa for Consumption.—It will be obvious that, if we know the a

under the crop, and have a trustworthy estimate of the average yield per acre, the aggregate home produce is ascertained by a very simple calculation. In determining the amount of the total produce available for consumption, allowance has to be made for the amount annually returned to the land as seed. For reasons formerly given, we have assumed $2\frac{1}{4}$ bushels per acre to be so returned to the land, and we do not propose to make any alteration in that estimate.

The Imports.—From the commencement of the period to which our inquiry relates we have, for the United Kingdom collectively, Returns, either of the net imports of wheat and wheat-flour, or of the imports and exports from which the net imports can be calculated. For the separate divisions of the country the Returns have not been so complete. But, as we are confining attention to the United Kingdom as a whole, this is immaterial for our present purpose. In the case of the United Kingdom, the records for the individual weeks or months are available; and from these the net imports have been calculated, not for the calendar years, but for the *harvest years*, that is, from September 1 of one year, to August 31 of the next.

The Population.—As the Registrar-General publishes an estimate of the population at the middle of the calendar year, for every year between one Census and another, it is easy to calculate, with sufficient accuracy for our purpose, the average number of consumers over each harvest-year. The middle of the calendar year being the end of June, and the middle of the harvest-year the end of February, the plan adopted has been to add to the number recorded for the preceding midsummer, two-thirds of the difference between that figure and the number given for the next midsummer, thus bringing the estimate up to the end of February. Of course, this can only be done after the second record is published, and the plan was not available in estimating the population of the current harvest-year soon after harvest each year; but the necessary corrections have now been made. The figures show some irregularity of increase immediately after the Census years, and at some other periods, presumably from a new factor being then adopted for the calculation of the annual increase of the population.

The Average Consumption of Wheat per head of the Population per Annum.—Previously to the publication of our former paper on this subject, a higher figure had been generally assumed than we were then led to adopt. For England and Wales, we founded an estimate of the average consumption per head of the population, on the calculation of eighty-six different dietaries, arranged in fifteen divisions, according to sex, age, activity of mode of life, and other *circumstances*; and the result so obtained was

compared with that arrived at on the basis of the population, and of the amounts of the available home produce, and of the net imports of wheat, each year. For Scotland, and for Ireland, it was only possible to found an estimate on the basis of population, and on the amounts of the home and foreign supplies. On these bases we estimated the average consumption of wheat, in the United Kingdom collectively, to be 5½ bushels per head of the population per annum, during the later years to which our inquiry related; and we have adopted that figure from that date up to the present time. This estimate, whether correct or not, has from that time been very generally adopted by other writers on the subject also. Its correctness, and its continued applicability, we propose to consider on the present occasion.

Thus, with regard to the area under the crop, the imports, and the population, we adopt, without modification, the same data or estimates as previously; but the basis of the estimates, and the results arrived at, in regard to the average produce of wheat per acre over the United Kingdom each year, and the estimates of the consumption per head of the population, we shall submit to examination, and to correction or otherwise, as the case may be.

As already said, the estimate of the *average yield of wheat per acre* over the United Kingdom is, each year, founded on the average produce obtained on certain selected plots in the field at Rothamsted, which has now grown the crop for thirty-six years in succession—without manure, with farmyard-manure, and with various artificial manures. There has been no change in the treatment of the unmanured plot, or of the dunged plot, since the commencement of the experiments in 1843–4. There were, however, some changes in the manures applied to the various artificially manured plots during the first eight years, from 1844 to 1851 inclusive. But, for the period of twenty-eight years, from 1852 up to the present time, two of the selected artificially-manured plots have respectively received exactly the same manure each year, and the third has done so for twenty-five years, as described below. The selected plots are—

Plot 3. Unmanured every year, experiment commencing 1843–4.

Plot 2. 14 tons farmyard-manure every year, commencing 1843–4.

Plot 7. Mixed mineral manure, and 400 lbs. ammonia-salts, each year, twenty-eight years, 1851–2, and since.

Plot 8. Mixed mineral manure, and 600 lbs. ammonia-salts *each year*, twenty-eight years, 1851–2, and since.

Plot 9. Mixed mineral manure, and 550 lbs. nitrate of soda, each year, twenty-five years, 1854–5, and since.

In forming the estimate of the average produce per acre of the country at large, the plan adopted has been to take the mean produce of the unmanured plot, of the farmyard-manure plot, and of the three artificially manured plots reckoned as one, and to reduce the result so obtained to bushels of the standard weight of 61 lbs. per bushel. As will be shown further on, experience has proved that this mode of estimate leaves but little to be desired as a means of computation of the average yield of the country over a number of years; but it has not been found to be equally applicable for each individual year. Careful comparison leads to the conclusion that the so-calculated average produce per acre on the selected plots gives somewhat too high a result for the country at large in seasons of great abundance, and too low a result in unfavourable seasons. Accordingly, as above referred to, in some seasons, instead of the actual average indicated by the experimental plots, a higher or a lower figure has been adopted; and, especially in the case of some of the recent bad seasons, a higher one has been taken.

Independently of any such admitted differences between the so directly calculated, and the actually adopted, estimates for individual years, the question arises—whether the average result indicated by the several selected plots remains as applicable as heretofore? or whether the produce of some is annually declining, or that of others annually increasing, irrespectively of the influence of season, so as to vitiate the continued applicability of such results for the purposes of such an estimate?

The Unmanured Plot.—There can be no doubt that the produce on this plot is gradually declining from exhaustion; and, independently of the evidence of diminishing produce, analyses of the soil, at different periods, show that there is a gradual diminution in the amount of nitrogen in it. Owing, however, to the great fluctuations in the amount of produce from year to year, dependent on the season, it is by no means easy to estimate the rate of decline due to exhaustion of the soil, as distinguished from that due to the seasons. In the first place, it is difficult to say what figure should be adopted as the standard produce of the plot, by which to compare the yield from year to year. The whole field was manured with farmyard-dung in 1839, and then grew turnips, barley, peas, wheat, and oats, before the commencement of the experiments in 1843–4. The plot then grew eight crops of wheat, to 1850–1, without manure, before the commencement of the period to which our present estimates refer. No doubt the land would suffer more or less exhaustion during those first eight years; but, as serving to counteract the tendency to decline

in yield from that cause, it happened that, taken together, those eight seasons were of considerably more than average productiveness; so that, perhaps, we may assume the average produce of those eight years fairly to represent the standard produce of the unmanured land independently of material exhaustion. That produce was equal to 17 bushels, at the standard weight of 61 lbs. per bushel. If now we calculate what should be the produce in each of the subsequent twenty-eight years, on the assumption that it fluctuated from the standard exactly in the proportion of the fluctuation from year to year of the adopted average yield of the country at large, and compare the result so obtained with the actual yield of the plot each year, we find that the latter shows an average annual deficiency over the twenty-eight years of 4⅜ bushels. According to this mode of calculation, therefore, this represents the decline of produce on the unmanured plot, irrespectively of season; and it may be observed that, supposing it to be uniform over the whole period, it would correspond to a rate of diminution, due to exhaustion, of between one-quarter and one-third of a bushel from year to year. It remains to be seen whether, with a return of good seasons, the decline will be as marked; and also whether, in time, a point will be reached at which the produce will remain constant, excepting so far as it is influenced by the fluctuations of the seasons.

The Farmyard-manure Plot.—If the unmanured plot is declining in yield and fertility, there can be no doubt that the farmyard-manure plot is increasing in fertility. Analysis at different periods shows that the surface soil has become more than twice as rich in nitrogen as the unmanured land. In fact, as we have shown on several occasions, a large amount of the constituents of farmyard-manure accumulates within the soil, and they are taken up very slowly by crops. It is, indeed, remarkable that, notwithstanding this great accumulation within the soil, the crops on the dunged plot never show over-luxuriance. During the last few years there has even been a considerable decline in produce, due to unfavourable seasons, which have greatly encouraged the growth of weeds, and especially of grass; whilst, owing to the wetness of the seasons, it has been quite impossible effectually to clean the land, and what has been done to that end has not been accomplished without injury to the crop.

If, as in the case of the unmanured plot, we were to adopt the average of the first eight years, from 1844 to 1851, to represent the standard yield of the farmyard-manure plot, irrespectively of material accumulation, the figure arrived at would be 28¼ bushels. *This is* certainly a surprisingly low produce to be obtained by

ual application of 14 tons of farmyard-manure per acre, t years in succession, and in seasons which, taken togeere of more than average productiveness. But if we iis as the standard produce of the plot; then calculate ould be the produce in each of the subsequent twenty-:ars, provided it fluctuated from year to year exactly in e degree as the average produce of the country at large; :n take the difference between this calculated produce ing by season alone, and that actually obtained each : ascertain the increase or decrease due to accumulation iure. On this mode of calculation we get an average increase due to accumulation of 5¼ bushels. If, on the and, instead of the average produce of the first eight re take the average of the whole thirty-six years of the tion of the dung, we get, instead of 28⅛ bushels, 32⅛ , as the standard with which to compare the annual :. Adopting this figure, and following the same line of ion as before to exclude the influence of season, we have age annual excess, due to accumulation, of only 1¼ bushel. :an be no doubt that, were it not for the adverse influence recent wet seasons, the estimated excess would be more ¼ bushels adopting the first standard, and more than el adopting the second. Probably the truth lies between ro figures: and, if so, it would appear that, up to the time at any rate, the gradually diminishing produce on ıanured plot, due to exhaustion, and the gradually in-; produce on the dunged plot, due to accumulation, mately balance one another.

Artificially-manured Plots.—Though obviously open to ın, in default of any better alternative, we adopt for lots the average produce of the twenty-eight (or twenty-:ars to represent the standard yield, irrespectively of ion or accumulation. Doing this, and excluding the :e of season by the same line of calculation as before, no evidence of material increase, or of material decrease, er of the plots receiving ammonia-salts, other than that season. The first fourteen of the twenty-eight years d a number of seasons of unusually high productiveness, : last fourteen a number of unusual deficiency. The :ions show, accordingly, an excess over the assumed d produce during the first half of the period, and a closely onding deficiency over the second half, in both the cases ımmonia-salts were used. Where the nitrate of soda was ed, there was, on the other hand, a somewhat greater ıcy over the first period than there was an excess over ond, *indicating for the* total period a slight deficiency.

Finally, taking the average of the unmanured plot, of the farmyard-manure plot, and of the three artificially manured plots reckoned as one, as is annually done for the purpose of our estimate; then correcting the result for each year as before, for the fluctuations of season; and comparing the results so obtained with the actual averages, the actual results show a very slight excess over the first half of the period, including more than an average of good seasons, and a somewhat greater, but still small, deficiency over the second period, including more than the average of bad seasons. The average of the whole indicates, therefore, no gain by accumulation, but, if anything, a slight loss.

Comparing the direct average of the experimental plots with that actually adopted as the average for the United Kingdom each year, the experimental plots indicate for the whole twenty-eight years about three-quarters of a bushel less per acre per annum than the actually adopted estimates founded upon them.

Taking the average of the twenty-eight years' adopted estimate of produce per acre as 100, the first column of the following Table shows the deviation from this general average for the whole period, over the first eight, the second eight, the third eight, and the last four, years of the twenty-eight; and the second column shows the deviation, from the same standard, of the average actual produce per acre on the selected plots:—

TABLE I.—SHOWING the DEVIATION over each separate Period from the adopted AVERAGE of the whole PERIOD taken as 100.

	Actually adopted Averages.	Averages of Plots, 3, 2, and 7, 8, and 9.
First 8 years, 1852–59	103	101
Second 8 years, 1860–67 ..	104	106
Third 8 years, 1868–75 ..	98	99
Last 4 years, 1876–79	89	71
Total Period 28 years..	100	98

So far as the annually adopted estimates are correct, the figures in the first column indicate the actual fluctuations in the average produce per acre of the country at large due to the characters of the seasons over each period compared with the others, and with the total period.

The first period of eight years included two of considerably over average, another over average, three rather under, and two very much under average. The result was, however, upon the

le slightly over the average of the twenty-eight years. The pted average produce showed 3 per cent. over the average ıe twenty-eight years, and 2 per cent. over the actual average he selected plots—a higher figure than the actual average ng been adopted in the case of the two years of very low luce.

'ithin the second period of eight years, there were two of highest yield over the twenty-eight years, two more somet over average, two under, and two much under average. his period highly productive seasons prevailed; the adopted age is 4 per cent. over the average of the twenty-eight years, the actual average on the selected plots is 6 per cent. over, per cent. higher than the adopted average.

ı the third period of eight years there was only one of really ı produce, two more were over average, one was under, and were considerably under average; the mean of the whole g under average. The adopted average for the period shows r cent. under the average of the twenty-eight years, whilst average of the experimental plots shows 1 per cent. under ıverage.

he last four years included only one over average, two under, one (1879) very abnormally under average. Over this od, the adopted average amounted to only 89 per cent. of for the twenty-eight years; and, with the unusual prevalence ad seasons, the experimental plots showed only 71 per cent., ıuch lower than the adopted average.

'hus, it appears that, in fairly average seasons, the mean luce of the experimental plots fairly represents the average luce; that in seasons of unusual abundance the experimental s indicate too high a figure; and that in seasons of great ciency they give too low a figure. Upon the whole, it is cluded that we have no better basis for estimating the rage yield of the country each year than that of the average luce of the same selected plots as heretofore relied upon; that, as heretofore, some judgment must be exercised each , according to the characters of the season, in deciding ther to adopt the actual figure indicated by the experimental s, or in which direction, and in what degree, it should be lified. It will, moreover, have to be considered from time ime, whether any reduction of area that may take place is in ter degree due to the elimination of districts where the soil, he climate, or the combination of the two, is the less, or the e, favourable for the crop; for it is obvious that, other things g equal, the average produce per acre of the remaining area increase or diminish accordingly.

The next point is to test, as far as the means exist to that end, the correctness of the estimates of the aggregate home produce, and of the consumption per head per annum, as given in our former paper for the first sixteen years, and as annually published as forecasts since that period.

In our annual estimates we have adopted a figure for the average produce per acre over the United Kingdom, calculated the aggregate produce, deducted from this the amount required for seed, and then estimated how much would be required, from stocks and imports, to make up the total requirement for consumption, this being reckoned at a fixed rate per head of the population. Now, however, we have the actual record of the imports each year, as a fixed element of the inquiry; and, adopting the same returns or estimates as to area and population as heretofore, the question now is—not what will be the imports, but how far the estimates of home produce have been correct? and how far these estimated amounts, minus the quantities required for seed, and plus the actual imports, give a total corresponding with the estimated requirement for consumption?

The following Table shows the averages, for the first eight, for the second eight, for the third eight, for the succeeding three, and for the total period of twenty-seven years, of—

1. The aggregate home produce of wheat, deduced by calculating the amount required for consumption (at the rate of 5·1 bushels per head per annum during the first eight years, and of 5·5 bushels in each subsequent year, as up to this time assumed), deducting from this the nett imports, and adding 2¼ bushels per acre for seed.

2. The aggregate home produce calculated according to the annual estimates of the average produce per acre, as previously published.

3. The difference between the estimate of total home produce founded on consumption and imports, and that founded on the annually adopted estimates of average produce per acre.

4. The average produce per acre, calculated from the aggregate home produce founded on the estimated requirements for consumption, and the imports.

5. The average produce per acre, according to the annually adopted estimates.

6. The difference between the average produce per acre calculated from the aggregate home produce deduced from consumption and imports, and the annually adopted estimates of average produce per acre.

.—COMPARING the ESTIMATES of HOME PRODUCE founded on re-ents for CONSUMPTION and IMPORTS, with those founded on the .y adopted ESTIMATES of AVERAGE PRODUCE per ACRE, over the KINGDOM.

	Aggregate Home Produce.			Average Produce per Acre.		
	Deduced from calculated requirements for Consumption and Imports.	According to Annually adopted Estimates of Average Produce per Acre.	Annually Estimated, + or − calculated according to requirements, &c.	According to Consumption and Imports.	According to Annually adopted Estimates.	Annual Estimate + or − Calculated.
or—	Quarters.	Quarters.	Quarters.	Bushels.	Bushels.	Bushels.
	14,390,956	14,310,779	− 80,177	28⅛	28	− 0⅛
	13,312,217	13,309,247	− 2,970	28⅜	28⅜	0
	12,403,525	12,684,765	+ 281,240	26¼	26¾	+ 0½
	10,540,029	11,116,910	+ 576,881	25⅝	27¼	+ 1⅝
	13,054,581	13,177,373	+ 122,792	27⅜	27⅝	+ 0¼

ing out of view for the present any consideration of the ible discrepancies which must appear between the results e two modes of estimate for individual years, it is obvious hether we compare the aggregate home produce founded requirements for consumption and on imports, with that d on the annually adopted estimates of produce per acre, pare the estimated average produce per acre itself arrived ie two different ways, there is, taking the average of the -seven years, comparatively little difference between the thus variously arrived at. The annually adopted estimates luce per acre over the United Kingdom give, however, her result.

obvious that, to bring out still more close conformity of from the two modes of estimate, we must either raise imate of requirement for consumption per head, or lower the average produce per acre over the United Kingdom ie of the years. Unfortunately, we have little else than ent to aid us in deciding between these two alternatives. ever, we compare the average result by the two methods rter periods—for the first, for the second, for the third ears, and for the last three years, of the twenty-seven, for le—it is seen that the results of the two estimates agree osely indeed for the first two periods of eight years each; it, for the third and fourth periods, those founded on the

requirements for consumption and the imports are considera lower than the average of the annually adopted estimates those periods. The fact is that, for each of the first two peric the estimated consumption was itself finally founded on estimated home produce and the imports of the periods ; so tl although there will be discrepancy in the results arrived at the two ways for individual years, there could not be mate disagreement over the whole of either of those periods. each of the last two periods, however, the estimate of consu tion per head has been annually adopted independently, as f cast, and the discrepancy between the results of the two mc of estimate for those periods has, therefore, a real significanc

Independently of the question of whether or not any rection in the estimates for individual years should be made, foregoing results would lead to the conclusion that the ac consumption per head, taken together with the amount consu by stock, has been greater over the last two periods than has t annually assumed. If now we assume the requirement per h to have been 5·6 bushels over the third eight years, and bushels over the last three years, instead of, as previou 5·5 bushels over those eleven years, this would bring the estimates into very much closer agreement. We should t have the average produce per acre per annum, over the Un Kingdom, for the respective periods as follows :—

TABLE III.

	Average Produce per Acre.	
	According to increased Consumption, and Imports.	According to Annually adopted Estimates.
	Bushels.	Bushels.
Average 8 years, 1852-3—1859-60 ..	28⅛	28
Average 8 years, 1860-1—1867-8 ..	28⅜	28⅛
Average 8 years, 1868-9—1875-6 ..	27	26¾
Average 3 years, 1876-7—1878-9 ..	27⅜	27¼
Average 27 years, 1852-3—1878-9	27¾	27⅜

It will be observed that, with the estimates of the average sumption per head raised as above supposed, the average prod per acre founded on consumption and imports is slightly hi over the last two periods than that founded on the annu adopted estimates. It must be borne in mind that the quan of wheat consumed by farm-stock is an unknown and vary *element*; and either the estimate of the consumption per *of the population* must be fixed to include the average consu

in other ways, or the annual estimates of produce per acre, of the aggregate home produce founded upon them, should ed those founded on consumption and imports. It may be arked that an increase of one-tenth of a bushel in the conption per head per annum would, if derived from home luce, represent an increase of one bushel per acre per annum the United Kingdom, assuming a population of 33,000,000, an area under the crop of 3,300,000 acres; figures which ely represented the actual facts a very few years ago. It is ous that, with an increasing population, and a diminishing under wheat, such an assumed increase in consumption per l would correspond to more than a bushel per acre.

able IV. (over-leaf) shows the amount of home produce reed for consumption within each harvest-year, as calculated by icting the nett imports from the estimated total requirement onsumption, adopting the increased estimates of consumpper head, as above assumed, for the last eleven years; and, omparison with the result so obtained, there is given the int of home produce available for consumption each year, rding to the annual estimates of the average produce per with 2¼ bushels per acre deducted for seed. The difference een the two is shown in the last column.

hen it is borne in mind that the first estimate (Col. 4) sents the requirement alone each year, and the second 5) the amount available for consumption from the estimated l crop each year, it will be obvious that agreement between wo estimates for individual years is not to be expected. amounts carried over from one harvest year to another will, urse, vary exceedingly according to circumstances, the ince of which cannot with any certainty be estimated. We , for example, no reliable information as to the quantity of e-produced wheat held in the farmer's hands, the quantity imed by farm-stock, or otherwise used, or the quantity of gn wheat held over in the granaries. Then, again, the l length of the period to be provided for, dependent on the ness or the lateness of consecutive harvests, has to be taken account.

eferring to the actual differences for individual years, as n by the figures in the last column of the Table (IV.), obvious that, whilst there may be, and frequently is, an ss of wheat available over that required for consumption in the harvest-year, there cannot be an actual deficiency. hout attempting to account for each individual difference, it be observed that the deficiencies which the figures indicate me of the earlier years would doubtless be compensated, at rate in part, if the balance were brought forward from the

Table IV.

Harvest Years; September 1, to August 31.	Total required for Consumption, at 5·1 bush. 1st 8 Years, at 5·5 bush. 2nd 8 Years, at 5·6 bush. 3rd 8 Years, at 5·65 bush. last 4 Years, per head per Annum	Imports.	Difference, required from Home Produce within each Harvest Year.	Home Produce available for Consumption according to Annual Estimates of Average Produce per Acre (2½ bushels per Acre deducted for Seed).	Available Home Produce according to Annual Estimates + or — calculated requirement within each Harvest Year.
	Quarters	Quarters.	Quarters.	Quarters.	Quarters.
1852-3	17,538,354	5,902,000	11,636,354	10,433,464	— 1,202,890
1853-4	17,607,719	6,092,000	11,515,749	9,337,546	— 2,178,203
1854-5	17,701,710	2,983,000	14,718,710	16,427,742	+ 1,709,032
1855-6	17,816,807	3,265,000	14,551,807	12,776,300	— 1,775,507
1856-7	17,932,364	4,112,584	13,819,780	13,007,453	— 812,327
1857-8	18,055,662	5,795,687	12,259,975	16,143,915	+ 3,883,940
1858-9	18,183,671	4,555,670	13,628,001	15,147,874	+ 1,519,873
1859-60	18,306,247	4,516,332	13,789,915	12,004,575	— 1,785,340
1860-1	19,874,968	10,023,968	9,851,000	9,956,012	+ 105,012
1861-2	20,025,576	9,099,455	10,926,121	11,175,183	+ 249,062
1862-3	20,165,510	9,205,086	10,960,454	12,882,069	+ 1,921,615
1863-4	20,287,594	6,991,270	13,296,324	16 881,807	+ 3,585,483
1864-5	20,419,321	5,500,705	14,918,616	15 179,783	+ 261,167
1865-6	20,547,130	7,313,026	13,234,104	12,950 305	— 283,799
1866-7	20,684,813	7,633,033	13,051,780	10 458 645	— 2,593,135
1867-8	20,830,600	9,015,543	11,815,057	8,545 890	— 3,269,167
1868-9	21,368,178	7,719,304	13,648,874	15,626 060	+ 1,977,186
1869-70	21,532,105	9,921,526	11,610,579	12,301 205	+ 690,626
1870-1	21,909,347	8,008,839	13,900,508	13,047 554	— 852,954
1871-2	22,224,385	9,316,600	12,907,785	0 382 493	— 2,525,292
1872-3	22,428,445	12,291 463	10,136,982	0 405 053	+ 268,071
1873-4	22,622,952	11,301 316	11,321,636	9,261,375	— 2,060,261
1874-5	22,840,258	11,705,255	11,135,003	12,898,085	+ 1,763,082
1875-6	23,082,333	13,860,079	9,222,254	9,033,000	— 189,254
1876-7	23,537,495	12,107,294	11,430,201	8,857,015	— 2,573,186
1877-8	23,826,133	14,408,628	9,417,505	10,039,073	+ 621,568
1878-9	24,058,216	14,145,649	9,912,567	11,698,672	+ 1,786,105
1879-80	(24,334,025)	(16,409,933)	(7,924,092)	(5,047,840)	(— 2,876,252)

Averages.

8 Years, 1852-59	17,892,820	4,652,784	13,240,036	13,159,859	— 80,177
8 Years, 1860-67	20,354,443	8,097,761	12,256,682	12,253,712	— 2,970
8 Years, 1868-75	22,251,000	10,515,548	11,735,452	11,619,358	— 116,09[illegible]
3 Years, 1876-78	23,807,281	13,553,857	10,253,424	10,198,258	— 55,171
27 Years, 1852-78	20,570,665	8,399,641	12,171,024	12,105,857	— 65,167

diately preceding years, the last three of which were as of more than average productiveness, and of lower than ge price, conditions which imply abundance. Then as to of the excesses. It may be mentioned in illustration that, ch of the four consecutive years 1862, 3, 4, and 5, there nore, and in two of them very much more, than the average ice over the country at large; and it was estimated that, at arvest of 1865, there still remained over from the extra-ary crop of 1863, and the abundant one of 1864, wheat to from one-third to one-half of an average crop; and that, at the harvest of 1866, some of the crop of 1863 remained ashed. It may, indeed, be stated generally, that as a rule xcesses follow, as they should, seasons of high productive- and the deficiencies seasons of low productiveness.

screpancies between the two results for individual years are, ct, inevitable; and the figures strikingly illustrate the ılty of the subject, so far as individual years are con-d. But if the bases of the estimates are correct, the results two methods should agree when averaged over a sufficient er of years. An examination of the averages for the ent periods, given at the foot of the table, will show that, the increased estimates of consumption per head for the wo periods, the agreement between the differently obtained s is really very close.

ıally, as to the questions—whether our previous estimates consumption of wheat per head of the population, over ırst two periods of eight years each, are correct? and ıer we are to conclude that there really has been an ısed consumption per head in the subsequent years?

ere can be no doubt that the average consumption per head ncreased in the United Kingdom as a whole since the lishment of free trade in corn; and there can be but little that it has done so less rapidly during the later, than g the earlier, years since that change. This will be the at any rate, with the much larger proportion of the total lation which is comprised within England and Wales; h the increased consumption has probably been developed in Scotland, and perhaps in Ireland also. The amount ımed will obviously vary according to the prosperity or wise of the people, to the price of wheat itself, and to that her articles of food also. With regard to the price of t, barring exceptional cases, there has been a general ncy to decline throughout the period to which our esti- refer. Independently of the influence of lower prices, and e increased prosperity of the masses of the population, ıg the circumstances tending to increase the consumption

of wheat in recent years may be mentioned the increased price of meat; whilst, among those tending to limit the rate of increase of consumption may be noted the fact that the proportion of the total wheat consumed which is derived from foreign sources is rapidly increasing, and the drier foreign wheats will undoubtedly yield a larger percentage of flour, and flour of better quality, than much of the home-grown grain.

As already explained, the estimates of consumption per head over the first sixteen years, although controlled by the calculation of numerous dietaries, were finally founded on the estimated amounts of home produce and the ascertained amounts of the imports; and they were calculated for the first half, and the second half of that period separately, in order to ascertain whether or not an increased rate of consumption were indicated. The result was that the so reckoned available supplies showed a consumption of about 5·1 bushels per head per annum over the first eight years, and of 5·5 bushels over the second eight years. Of course, even supposing that the estimates of the available supplies over the whole period were correct, and that there was a considerable increase in the rate of consumption during the period, it is not to be assumed that there was the sudden rise from the first to the second eight years, which taking the averages over those separate periods shows. It is, indeed, doubtful whether the estimates of consumption per head over the earlier years, as deduced from the amounts estimated to be available from the home produce and the imports, may not be somewhat too low, due to an under-estimate of the area under the crop in those years, and to no allowance being made for stocks brought forward from previous years. But, as no data exist upon which to base a trustworthy correction, the safer alternative seems to be simply to call attention to this probability.

Then, again, a careful consideration of our annual estimates of produce per acre subsequent to the first sixteen years, leads to the conclusion that some are more probably too low than too high. For 1866 and 1867, for example, our own estimates are lower than those of some others; and that for 1867, at any rate, may we think probably be somewhat too low. But here, again, there is lack of sufficient evidence to justify an alteration.

Upon the whole, we are disposed to conclude that our estimates of consumption per head during the first period of eight years may be somewhat too low. We also conclude that our previously published estimates of consumption for the years subsequent to the first sixteen, are more probably too low, than that our estimates of average produce per acre, and of aggregate *produce* founded upon them, are too high. For the reason

ı, however, we adopt our previous estimates of average ıce per acre each year without change. We also adopt ırevious estimates of consumption per head for the first two ds of eight years each without change. But, for the third d of eight years we assume the consumption to have been : rate of 5·6 bushels per head, and for the last three years e rate of 5·65 bushels, instead of 5·5 bushels over those n years, as previously reckoned.

:cordingly, until further experience should indicate further ɟe to be necessary, we propose to adopt 5⅝ bushels as the ge consumption per head of the population per annum, the United Kingdom.

.ble IV., p. 16, shows the estimated aggregate consumpof wheat in each year, and the amount of it derived from : and foreign sources respectively; and Table V., which rs (facing p. 20), brings to one view the particulars of the ıated home produce, of the imports, of the consumption per , of the average 'Gazette' price per quarter, and of the of wheat (at the average 'Gazette' price), in the United dom, in each of the 27 (or 28) harvest-years, from 1852–3 ' the present time.

ferring to the upper portion of the table for all details, and : text for further information respecting some of them, the al tendency of the changes which have taken place within ıeriod of our review is clearly indicated in the average s over the periods of 8, 8, 8, 3, and 27 years, given at the ıf the table.

cording to the figures, the area under wheat was about 20 :nt. less over the last 3, than over the first 8 years, of the 27. e average produce per acre over the United Kingdom was lerably less over the last two than over the first two ls. It amounted to only 27⅝ bushels over the whole ars, as compared with 28¼ bushels, which we had previously ed to represent the average produce per acre of the country ɟe.

ing to the reduced produce per acre in recent years, the ɟate home produce has reduced in a somewhat greater : than has the area under the crop.

: annual imports (less exports) averaged about three times ch over the last 3, as over the first 8, of the 27 years.

: total consumption of wheat per annum has increased from :rage of about 18 million quarters over the first 8 years, to ' 24 million quarters over the last 3 years.

:ording to the figures, the average consumption per head ınum was only about 5·1 bushels over the first 8 years, and ıunted *to 5·64 bushels* over the last 3 years.

The price of wheat per quarter has declined from a of 57*s.* 8*d.* over the first 8 years (including the peri Crimean War) to 49*s.* over the last 3 years.

The annual value of the home produce available for tion has declined from an average of nearly 38,000,(the first 8 years, to less than 25,000,000*l.* over the last

The annual value of the imported wheat has increas average of little more than 13,000,000*l.* over the first { more than 33,000,000*l.* over the last 3 years.

The annual value of the total wheat estimated to be has ranged from under 40,000,000*l.* to more than 71,(and it has increased from an average of about 51 over the first 8 years, to more than 58,000,000*l.* ov 3 years.

The average annual cost of wheat per head has reduced in the later periods; and it has been 36*s.* 2*d* 27 years.

Over the whole period of 27 years, 40·2 per cent. of consumed has been derived from imports; and the an plied from foreign sources has increased from an 26·5 per cent. of the total over the first 8 years, to 57·] of the total consumed over the last three years, of the

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NOTE BY THE AUTHORS.

In Tables—II. p. 13, III. p. 14, IV. p. 16, and V., facing p. some alterations from the figures relating to the later years as corresponding Tables in the 'Journal of the Statistical Society' (and in the 'Journal of the Royal Agricultural Society,' (vo Part II.), from which latter this is otherwise a reprint. For t the corrections are required owing to the imports and exports o having been originally taken from the 'Trade and Navigatic Returns, in which the *British* exports of wheat and wheat-meal not given. These are now taken from the weekly 'Gazette' Ret narily the amounts of such exports are not very material, but they are so, as, for instance, about the time of the Franco-Germa corrections now made in the Tables, which make the records complete and exact, have necessitated a few slight alterations in they do not affect any of the main conclusions drawn.

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ARVEST-YEARS, 1852-3 to 1879-80 inclusive.

onsumption rice). Total	Value of Wheat estimated to be Consumed † (At Average 'Gazette' Price). Total.	Per Head.		Per Cent. of Total available. From Home Produce	From Imports.	Harvest-Years, September 1 to August 31.
£	£	s.	d.			
36,414,472	39,095,914	28	5	63·9	36·1	1852–3
56,258,553	64,194,918	46	6	60·5	39·5	1853–4
68,018,475	62,029,742	44	8	84·6	15·4	1854–5
59,285,971	65,847,949	47	2	79·6	20·4	1855–6
51,431,444	53,871,810	38	4	76·0	24·0	1856–7
52,289,385	48,032,661	30	5	73·6	26·4	1857–8
43,019,404	39,701,015	27	10	76·9	23·1	1858–9
39,856,688	44,163,821	30	9	72·7	27·3	1859–60
55,194,695	54,904,599	38	0	49·8	50 2	1860–1
58,965,405	58,241,050	40	0	55·1	44·9	1861–2
52,641,052	48,061,204	32	9	58·3	41·7	1862–3
48,939,808	41,589,568	28	2	70·7	29 3	1863–4
41,447,145	40,923,723	27	7	73·4	26·6	1864–5
47,112,244	47,772,077	32	0	63·9	36·1	1865–6
54,576,562	62,399,183	41	6	57 8	42·2	1866–7
60,001,563	71,171,217	47	0	48·7	51·3	1867–8
58,363,410	53,420,445	35	0	66·9	33·1	1868–9
51,297,471	49,703,276	32	4	55·4	44·6	1869–70
57,027,731	59,337,815	37	11	62·0	38·0	1870–1
55,732,017	62,876,489	39	7	52·7	47·3	1871–2
65,063,346	64,294,876	40	2	45·9	54·1	1872–3
62,973 241	69,282,791	42	10	45 0	55·0	1873–4
54,844,945	50,914,742	31	3	52·4	47·6	1874–5
52,558,694	52,993,190	32	2	39·5	60·5	1875–6
57,215,093	64,237,747	38	7	42·2	57·8	1876–7
62,137,907	60,558,088	35	11	41·1	58·9	1877–8
53,734,651	50,021,041	29	4	45 3	54·7	1878–9
(49,442,285)	(56,069,649)	(32	6)	(23·5)	(76·5)	1879–80
50,821,174	51,492,229	36	9	73·5	26·5	Av. 8 Years, 1852–'59.
52,359,809	53,132,828	35	11	59·7	40·3	Av. 8 Years, 1860–'67.
57,232,607	57,852,953	36	5	52 5	47·5	Av. 8 Years, 1868–'75.
57 695,884	58,272,292	34	7	42 9	57·1	Av. 3 Years, 1876–'78.
53,940,606	54,616,332	36	2	59·8	40·2	Av. 27 Years, 1852–'78.

1 5·65 the next three years.

[To *face* Page 20.

[*From the* PROCEEDINGS OF THE ROYAL SOCIETY, No. 205, 1880.]

"Agricultural, Botanical, and Chemical Results of Experiments on the Mixed Herbage of Permanent Meadow, conducted for more than Twenty Years in Succession on the same Land. Part II. The Botanical Results." By J. B. LAWES, LL.D., F.R.S., F.C.S., J. H. GILBERT, Ph.D., F.R.S., F.C.S., F.L.S., and M. T. MASTERS, M.D., F.R.S., F.L.S. Received June 17, 1880.

(Abstract.)

PART II.—*The Botanical Results.*

In Part I ("Phil. Trans.," Part I, 1880), under the title of the "*Agricultural Results*," a general description of the experiments, with full particulars of the conditions of manuring of each of the more than twenty plots, was given. The effects of each condition of manuring on the character of growth of the herbage, as illustrated in the quantities of produce yielded, and in the amounts of nitrogen and of mineral matter taken up, on each plot, were also fully considered. But, so varied were the components of the mixed herbage, both as to the species grown, and as to the character of development of the plants, that, to render the "*Agricultural results*" sufficiently intelligible, and to prevent misconception, if the element of quantity only were taken into account, it was found necessary to describe, in general terms, the differences in the botanical composition, in the character of development, and in some points in the chemical composition of the produce also. The object of the present section is to describe and discuss, more in detail, what may be called the *botany* of the plots; that is, to show both the normal botanical composition of the herbage, and the changes induced, by the application of the different manuring agents, and by variations in the climatal conditions of the different seasons; and, as far as may be, to ascertain what are the special characters of growth, above-ground or under-ground, normal or induced, by virtue of which the various

species have dominated, or have been dominated over, in the struggle which has ensued.

The method of taking the samples, and of conducting the botanical analyses and observations, is described. The characters of the seasons in which complete botanical separations were made, as well as those of some of the seasons leading up to the years of separation themselves, are discussed. The flora of the collective plots is described; and the organization by means of which the constituent plants may maintain themselves, or succumb in the competition, is considered. The characteristics of the individual dominant plants are pointed out; and, finally, the botany of each of the twenty-two plots is fully detailed, and the changes induced, by season or manuring, are discussed.

HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE.

BREAD REFORM

LETTER FROM DR. J. H. GILBERT, F.R.S., TO THE SECRETARY OF THE SOCIETY OF ARTS.

[From the *Journal of the Society of Arts*, January 21, 1881.]

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1881.

Dr. J. H. Gilbert, F.R.S., writes to the Secretary of the Society regretting his inability, on account of pressure of other work, to read a paper at the Society of Arts during this present Session, and goes on to say, "If I had any spare time for such a purpose, I should be disposed to discuss the important food question of the so-called bread reform. Many years ago Mr. Lawes and myself went somewhat fully into some of the points involved (*Journal of the Chemical Society*, vol. x., 1857). We showed the distribution of the nitrogen, the total mineral matter, the phosphoric acid, &c., in the different mill products from wheat grain. It is true that about three-fourths only of the total nitrogen of the grain are found in ordinary bread-flour, the remaining one-fourth or so being retained in the usually excluded portions, which latter are richer in nitrogen than the flour. But it has long been known that a considerable part of the nitrogenous matters of the excluded portions is not in the same condition as those in the flour; and it is stated that they are in an inferior degree digestible and available. Recent investigations show that only from two-thirds to three-fourths exist in the albuminoid condition; and it is as yet not settled whether, or in what degree, the non-albuminoid nitrogenous bodies are of nutritive value. So far as they are not, the value of the excluded portions will be proportionately reduced (so far as this is dependent on the nitrogenous compounds), and it may be even lower instead of higher, for a given weight, than in the flour. Of the phosphoric acid of the grain, it may be said that not more than about one-third will be found in the bread-flour. And, although I am not aware that the point has been proved, it may be that the flour is in a greater degree deficient in a due proportion of phosphoric acid than of nutritive nitrogenous compounds; and, if this be the case, it is a question whether it would not be better to add phosphoric acid in the process of bread-making (as is sometimes done in America), than to include the whole of the more phosphatic portions of the grain. For, if these were supplied in a coarsely-ground state, there would be waste of food by its passage through the body unused; and, if so finely ground as to avoid the aperient action, it is a question whether evil would not then arise from the excess of earthy (and especially magnesia) phosphate, causing accumulation and concretion. Indeed, notwithstanding the exclusion of so much of the nitrogen and phosphoric acid of the grain from ordinary bread-flour, we nevertheless came to the conclusion that such flour was better food than whole-meal bread, for the reasons that the nitrogenous matters of the excluded portions were of lower nutritive value; that those portions contained a considerable amount of indigestible woody matter; and that the branny particles so increased the peristaltic action as to cause the passage from the body of a large amount of the food unused. In reference to the points which are now again brought so prominently forward, we said, in the paper above referred to (pp. 33, 34):—

"'The higher per-centage of nitrogen in bran than in fine flour has frequently led to the recommendation of the coarser breads as more nutritious than the finer. We have already seen that the more branny portions of the grain also contain a much larger per-centage of

ineral matter. . . . . It is, however, we think, ery questionable whether, upon such data alone, a valid pinion can be formed of the comparative values, as ood, of bread made from the finer or coarser flours from ne and the same grain. . . . . Again, it is an ndisputable fact that branny particles, when admitted nto the flour in the degree of imperfect division in which our ordinary milling processes leave them, very onsiderably increase the peristaltic action, and hence he alimentary canal is cleared much more rapidly of its ontents. It is also well known that the poorer classes lmost invariably prefer the whiter bread; and among some f them who work the hardest, and who, consequently, would soonest appreciate a difference in nutritive quality navvies for example), it is distinctly stated that their reference for the whiter bread is founded on the fact hat the browner passes through them too rapidly, con-equently before their systems have extracted from it as much nutritious matter as it ought to yield them. It is reely granted that much useful nutritious matter is, n the first instance, lost as human food, in the bandonment of 15 to 20 per cent. of our wheat-rain to the lower animals. It should be remem-ered, however, that the amount of food so applied s by no means entirely wasted. And further, we hink it more than doubtful, even admitting that an ncreased proportion of mineral and nitrogenous consti-uents would be an advantage, whether, unless the branny articles could be either excluded, or so reduced as to revent the clearing action above alluded to, more utriment would not be lost to the system by this ction than would be gained by the introduction into he body, coincidentally with it, of a larger actual mount of supposed nutritious matters. In fact, all ex-erience tends to show that the state, as well as the hemical composition of our food, must be considered; n other words, that its digestibility, and aptitude for ssimilation, are not less important qualities than its ltimate composition.'

"Of course, if the branny portions were reduced to perfect state of fineness, and it were found that this revented the aperient action, and that other evils were ot induced, or, better still, if more of the food material an be separated from the bran, and in either case ithout more cost than the saving would be worth, here might be some advantage. But, to suppose that hole wheat meal, as ordinarily prepared, is, as has enerally been assumed, weight for weight, more utritious than ordinary bread-flour, is an utter fallacy, unded on theoretical text-book dicta; not only en-rely unsupported by experience, but inconsistent with . In fact, it is just the poorer fed and the harder orking that should have the ordinary flour bread ather than the whole-meal bread as hitherto prepared, nd it is the over-fed and the sedentary that should ave such whole-meal bread. Lastly, if the whole rain were finely ground, it is by no means certain hat the percentage of really nutritive nitrogenous atters would be higher than in ordinary bread-flour, nd it is quite a question whether the excess of earthy hosphates would not then be injurious."

Dr. Gilbert adds that Mr. J. B. Lawes concurs with im in the opinions stated.

FERTILITY.

BY

J. B. LAWES, LL.D., F.R.S.

DAVID BOGUE,

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STAMFORD STREET AND CHARING CROSS.

THE substance of the following pamphlet has appeared in a series of letters recently published in the 'Agricultural Gazette.' The subject has been already treated in a more scientific manner by Dr. Gilbert in his opening address as president of the chemical section of the British Association last year. My object has been to bring out in a different form, adapted for a more extended circle of readers, certain conclusions, the result of investigations at Rothamsted, which at the present time have a most important bearing on practical agriculture.

J. B. LAWES.

ROTHAMSTED,
June, 1881.

FERTILITY.

We learn from geology that the world which we inhabit has passed through great changes, extending over vast periods of time. Compared with these periods, the existence of man in the world, however far back it may ultimately be traced, is quite a recent occurrence.

Whatever difference there may be in our views respecting the origin of species and the law of development, there can be none respecting the necessity of a creation of vegetable life, previous to that of man and animals as they now exist. They both derive their food from plants, and even the carnivoræ are indirectly dependent upon vegetation, as the flesh which they eat is formed by plant-eating animals.

Amongst the many changes produced upon the earth by man, those that affect vegetation are full of special interest. In our study of the lives and habits of animals, some of their operations appear to be the result of reason rather than instinct. For instance, the storing up of food for a winter supply

appears to be an act of intelligence and forethought. It may be observed, however, that, previous to the appearance of man, the vegetation as it existed upon the earth furnished the sole supply of food to every living creature. It was reserved for the higher intelligence of man to destroy this existing vegetation, and, in its place, substitute one more suitable to his wants.

At what period of the history of the human race the cereal grains first formed part of their food will probably never be known; there is, however, evidence to show that grain was used by pre-historic man, and at the present time, in one form or another, the cereal crops constitute the greater portion of the food of the world's population.

So entirely are we dependent upon the seed of these annual plants, that if we could imagine a year in which no crop ripened its seed throughout the world, the result would be that the greater part of the population would starve to death. At the same time so artificial are the circumstances attending the growth of these plants, and so entirely is their existence dependent upon the care and attention of man, that without such care they would become again as rare as when man discovered their valuable properties.

Perennial vegetation is the natural vegetation of the earth, and so great are the efforts of Nature to assert her rights, that if we allowed one of our fields

of corn to shed its seeds, and the same thing to happen as regards the annual weeds—which grow so abundantly among the corn owing to our destruction of their natural enemies the perennial weeds—it would only be a question of a few years, more or less, before the soil of the field thus left to its fate, would be again covered with perennial vegetation; while the annual plants would either be entirely extirpated or only exist as rare specimens.

Although man can live upon food which does not contain starch, still it may be said that the daily want of every human being, from the time he can crawl until he goes into his grave, is so much starch. It constitutes the great bulk of the daily food of those who labour in all countries, and it is never absent from the diet of the wealthy, although their table may be covered with dainties furnished from every quarter of the globe. The cereal grain crops are the great starch-producing plants; the potato, which has on this account become a portion of the daily food of many nations, being the only other plant that can at all compare with them in this respect.

The vast deposits of coal found in various parts of the world inform us that the earth has been covered with vegetation, which has been destroyed and renewed over and over again. The agriculturist has no direct interest in this vegetation, beyond the fact of its furnishing him with a supply

of fuel, and a small amount of manure. It is far otherwise, however, with the vegetation that exists, or has existed upon the earth since the last great geological changes took place, and the continents and seas assumed somewhat the position in which we now find them.

The natural vegetation of the earth, whether it be of forest, moor, or pasture, is chiefly perennial, and produces woody matter not adapted for food, or with the food ingredients so mixed up with indigestible matter as to be quite unfit to be acted on by the human stomach. Unless, therefore, man calls in the aid of an animal stomach to do the work of separation for him, his first step must be to destroy this existing vegetation.

We have been so long accustomed to cultivated fields in this country, that we can hardly realise that they ever existed in any other state than that in which we see them at present. In the United States, however, millions of acres are being brought into cultivation every year. We see there, agriculture advancing—to use an expression which our greatest statesman applied to our commerce a few years ago—by leaps and bounds, so that our British farmers seem in a fair way to be swamped by the competition; while in Ireland and in India, we have a population pressing so severely on the resources of the soil, as to make the question of food one of paramount importance to our statesmen. I think, therefore, that the question

"What is fertility?" is not otherwise than an appropriate one to consider at the present moment, and with this view will now proceed to make some observations on the subject.

If we took a quantity of rocks, such as we find in various parts of the earth's surface—granite, slate, quartz, limestone, &c.—and, after grinding them to different degrees of fineness, were to mix them together in different proportions, we could from the known composition of these various rocks, produce soils which would contain the most important mineral constituents of plant food in very different proportions. Assuming that we purposely made one soil as rich as we could in this food, one as poor as we could, with two others in intermediate stages, and we then left them exposed to the ordinary influence of sun and rain—I am here assuming the experiment to be tried upon several acres, and the artificial soil to be several feet deep—we should find that the seeds of plants carried by the winds and other agencies would spread and grow upon these soils with very different degrees of rapidity; and, assuming that we were able to watch the process for thousands of years, we might see several remarkable changes in the character of the vegetation. The surplus of the winter store of acorns laid up by a mouse might give rise to a forest of oaks, thick enough to destroy all the previous vegetation of grass; and again an accidental fire or a hurricane might

sweep away the forest vegetation, to be replaced by growth of some other kind.

The character and amount of the vegetation would differ greatly on the different soils, and the largest amount would be found on the soil where the plant could get the largest amount of food.

There being no carbon or combined nitrogen in the soil, the first plants would be entirely dependent upon what they could obtain of these substances, directly or indirectly, from the atmosphere. Rain-water always contains ammonia, and the plant and the soil may condense a certain further amount from the atmosphere; but growth, even in the soil richest in mineral food, would at first be small, as the decomposition of carbonic acid and fixation of carbon would be limited by the amount of combined nitrogen which the plant could obtain from the sources mentioned above; and it would be much greater where the most abundant mineral food existed, as every particle of the available nitrogen would be there used up; while where there was less mineral food, some of the combined nitrogen might pass through the soil and be lost.

Each year a certain portion of the vegetable growth dies off: leaves and branches fall, and portions of the roots decay. Part of the organic portion which falls upon the surface of the ground, returns again to the atmosphere, but a certain part remains, and added to that which decays underground, becomes

available for future growth. The atmosphere of the soil, which at first differed little from that which exists above it, becomes highly charged with carbonic acid, which decomposes the minerals in the soil, and thus, year by year, more and more of the nitrogen, collected by each generation of plants, becomes available for the generation that succeeds it.

This carbonaceous organic matter, under the general term Humus, was considered by the chemists in the early part of the present century to be the main source of fertility. The late Baron Liebig turned this idea into ridicule, and the word has almost been forgotten.

Under the term humus I include all those organic compounds in the soil which have gone through certain stages of decay since they formed parts of living vegetation. These compounds may be distinguished from living vegetation by their containing a larger proportion of nitrogen to the carbon.

Upon the greater number of ordinary soils the proportion of both carbon and nitrogen becomes less and less as we penetrate below the surface, consequently these substances must have had their origin in vegetation which had once grown upon the surface. Some soils which are called alluvial possess a subsoil fertility which appears to have been a deposit derived from the remains of vegetation washed from other soils. Fertility is, therefore, due to the organic residue of previous generations of plants, mixed with certain

mineral substances, the most important of which are phosphoric acid and potash.

As the annual rainfall in most parts of the world is in considerable excess of the evaporation, it is evident that those substances which I propose to designate as the stock of fertility in a soil must exist in a comparatively insoluble form, or they would have been washed away.

In regard to potash and phosphate of lime, we may assume that they are dissolved by secretions from the plant when the roots are in direct contact with them. Humus may be taken up in a similar manner, and by some plants more readily than by others. Still, it is not until the nitrogen of the humus has assumed the form of nitric acid that its full effect upon vegetation is realised.

A short time ago Schlösing proved that nitrification was due to the action of a minute organism which abounds in our soils. Under favourable conditions of temperature and moisture, nitric acid is produced with great rapidity; it has been proved in regard to the yeast plant (which converts sugar into alcohol and carbonic acid) that, like our ordinary crops, its growth depends upon a supply of mineral food. We know the nitrifying plant cannot carry on its work unless it is furnished with alkaline substances to neutralise the nitric acid formed. If, as may be the case, it requires alkalis and phosphates, we can explain why it is that the waters

passing through peaty soils does not contain nitric acid.

Under whatever conditions the nitric acid may have been produced, there is no doubt, however, that its efficacy as an agent of vegetable growth is very great; in fact, a farmer is often willing to give the value of a bushel of wheat for 5 or 6 lbs. of nitrogen in this form. Every one must have noticed how difficult it is to keep land free from weeds; even our roads and gravel walks, if left undisturbed, soon become covered with vegetation. As a further illustration I may mention that upon the platform of the station which I frequent a number of minute holes exist in the asphalt, owing to the escape of small bubbles of air when it was in a plastic state, and in each of these minute holes a small plant has taken up its residence.

When the pressure of the atmosphere was first discovered, but before the cause was known, the philosophers of the day pronounced that it was due to Nature's abhorrence of a vacuum. A few years ago no more rational explanation could have been given for the persistent efforts of Nature to cover the earth with vegetation; but modern science has thrown more light on the subject. Boussingault placed some garden soil, rich in organic nitrogen, but containing very little nitric acid, in a closed glass vessel: it was moistened and exposed to a temperature favourable to nitrification, and was frequently

stirred: at the end of a few months this artificial fallow had lost one-half of its carbon, and a formation of nitric acid had taken place, which, if calculated on an area of an acre, would have been equivalent to several hundred pounds. In an ordinary winter most of this nitric acid would be entirely washed out of the soil. We learn from this that vegetation prevents the escape of nitric acid, and stores it up as food products; then finally, when vegetation decays, it assumes the form of insoluble compounds such as humus.

Independently therefore of the removal of food products from the soil, which is the main object of cultivation, the constant stirring of the soil brings into activity more of the inactive ingredients, while the cultivation of annual plants—by leaving the soil so long without vegetation—is followed by large losses by drainage.

We now come to the question, if fertility is the result of accumulations, due to previous generations of plants, what is exhaustion?

In this term I intend to include all those operations of agriculture, the result of which is to reduce the capital stock of fertility which the soil contained when first brought into cultivation. The aim and object of agriculture is directed to this end: and that the complete exhaustion of the soil is not sooner effected is not due to any moderation on the part of the cultivator, but rather to the resistance which the

soil itself offers to the too rapid removal of its treasures.

At Rothamsted, portions of seven fields have been under careful experiment, for periods extending, in one instance to forty, and in all to more than twenty years. In addition to numerous experiments upon other parts of the farm, we have about 50 acres devoted to the continuous growth of the ordinary farm crops, both separately and in rotation.

In all the Rothamsted experiments, portions of each field have received no manure of any sort; while upon other portions the manures we apply are used continuously upon the same plots of land, and we thus get some idea of what is going on in the soil. Although not quite so interesting to practical farmers as some of our experiments, those in which the crops are grown continuously without manure of any sort, require to be very carefully studied; for, as the claims of tenants for unexhausted fertility are becoming more and more recognised, the time seems to have come when some effort should be made to draw the line between the natural fertility inherent in our soils, which is given in exchange for rent, and the additional fertility which the tenant brings upon the land at his option, but cannot altogether remove.

Many think that the original fertility of soils which have been in cultivation for centuries, has long since been exhausted; and that the crops now grown are due to the manure applied by the existing cultivator.

Before going into this question, on which I may have more to say later on, I will attempt to give some idea of the changes which have taken place since the land at Rothamsted was first brought into tillage, to the date when our experiments commenced; and again from that period to the present time.

I have before mentioned that all land was originally under vegetation, which was almost entirely perennial. In the earliest days of agriculture of which we have any record, the system adopted appears to have been to break up the woodland, moor, or rough pasture and take several corn crops in succession, until the produce did not repay the cost of the seed and cultivation; the land was then allowed to rest for some considerable time, when the same process was repeated. The exhaustion of the soil under this system would not be very rapid.

At what period my land was first brought into arable cultivation it is impossible to say, but at Rothamsted I have records which prove that wheat, and other corn crops were grown 250 years ago upon the same fields which are now under experiment; there are, however, no data to show how often a field was cropped in succession.

Speaking of a period much more recent than that to which I am referring, Macaulay says that the total yield of grain in Great Britain did not exceed 5,000,000 qrs. annually. Whatever might be the date at which

my fields were first brought into arable cultivation, it is probable that they were previously in a state of rough pasture with trees interspersed. On the south-east side, and forming part of the field, which has been under wheat experiments since 1844, there is rather more than an acre of pasture left, and extending the whole length of the south-west side of the same field there is also an unusually broad strip of grass, whence probably the field derived its name of Broadbalk. Adjoining the wheat field is an enclosure containing a few acres of pasture, which, judging from the character of the trees growing upon and close by it, has probably been undisturbed for centuries, and possibly may never have been in arable cultivation at all.

The soil of the pasture land in Broadbalk field, as also of that in the adjoining enclosure, have been submitted to careful analyses, and we find that they do not differ materially from each other. After removing all vegetable matter, roots, &c., amounting to several tons in weight per acre, the first 9 inches of the finely sifted mould contain 5700 lbs. of nitrogen, while the second 9 inches contain about 2500 lbs. more. In these experiments the analysis was not carried below 18 inches, but in another plot of pasture, of the same character, a short distance off, the analysis has been carried to a depth of 54 inches from the surface. Between 18 and 54 inches the nitrogen gradually declines; still, the quantity

between these two latter depths would amount to about 5000 lbs. per acre, or about 1 lb. to every cubic yard of soil. If we assume the surface soil to be 9 inches deep, we have 5700 lbs. of nitrogen in the surface soil, and 7200 lbs. below it, making altogether nearly 13,000 lbs. per acre within reach of the roots of some of our agricultural crops. This nitrogen, with certain minerals, forms the stock of fertility which could be drawn upon by those who first commenced growing arable crops.

The Rothamsted experiments had been carried on for some years before we attempted to sample and analyse soils, consequently the composition of my arable land, at the time it was first brought under experiment, is not based upon actual analyses; still, the analyses made since that period in the various fields have been so numerous that it is not difficult to fix, within some reasonable limits, the original composition of the surface soil. I am disposed to estimate the amount of nitrogen in the first 9 inches of the Broadbalk soil in 1840 at about 3000 lbs. per acre; the second 9 inches at between 2100 and 2200 lbs.; this would give a total stock of 5100 to 5200 lbs. per acre, which shows the very considerable reduction of about 3000 lbs. per acre in the amount of nitrogen contained in the arable land, as compared with that contained in the pasture.

I may observe there is nothing new in the fact that pasture contains a much larger stock of fertility than

the crop to draw upon than arable land. Mr. Caird, for instance, while discussing the possibility of our foreign supply of wheat coming to an end, refers to the stock of fertility existing in our pastures which might be rendered available. It is also further confirmed by the saying that the conversion of pasture into tillage makes a man; and if, as is certainly the case, the accumulation of the lost nitrogen in the soil is necessary to the existence of a pasture, we can readily understand that the converse process of converting arable land into pasture might be said to break a man. My present object, however, is to attempt to give some definite form to the term fertility; it is true I have only brought into my calculation one of its elements; but it will be seen, as we go on, how very important this element is.

There is every reason to believe that the nitrogen in the soil which lies below the depth of 9 inches is available for vegetation, still the amount of roots which penetrates below this depth is so small, as compared with the number of those that feed nearer the surface, that any reduction which may occur in the amount of the nitrogen at the lower depth must be comparatively small, and difficult to estimate by analyses unless periodically taken at very long intervals of time; the measurement of such changes as may occur must therefore be left as a legacy to a succeeding generation.

Since 1839 the Broadbalk field has grown one crop of barley, one of peas, one of oats, and thirty-eight crops of wheat. In 1846, 1856, 1865, 1868, and 1899, the soil of various parts of the field was analysed, and it is from the data thus furnished that my estimates are made.

In a lecture delivered by Dr. Gilbert in the South Kensington Science Conferences in 1876, he gave in a table the amount of nitrogen removed in the unmanured produce of wheat and straw as follows:—Eight years 1844–51, 25 lbs. per acre per annum; twelve years 1864–75, 16 lbs. per acre per annum.

In a recent paper on the home produce, consumption, imports, and price of wheat, we estimated the annual decline in the yield of the unmanured wheat crop at from one-third to one-quarter of a bushel per acre per annum. This in forty years would be equal to from 10 to 13 bush. as the reduction of the crop due to exhaustion.

With regard to the nitrogen in the soil, each analysis shows a reduction in the amount per cent. as compared with that which preceded it. The difficulty consists in fixing the actual amount of such reduction. I am disposed, however, to estimate it at from 1000 to 1200 lbs. per acre during the forty years, which would be considerably more than the amount of nitrogen carried off in the crops of wheat.

From what I have previously said respecting the production of nitric acid, and its liability to be washed

ıt of the soil by drainage in the absence of vegeta-on, it might be expected, in regard to the continued rowth of a crop like wheat—which ceases to collect od from the soil early in the summer—that con-derable losses would have taken place by such rainage in the earlier periods of the experiment. nfortunately, however, we had no drainage water llected from the field at those periods. At the esent time the composition of the drainage water the unmanured land rather indicates that the loss nitrogen by drainage is not more than what we ight expect would be supplied by the rain-water ling upon the land.

To sum up this part of the subject, we have idence of a very large loss in the accumulated ck of nitrogen, based upon the assumption that my ıd was originally pasture; there is a further large ss during the period in which the land has been ıder experiment and growing unmanured corn crops. ıe crops are declining; the amount of nitrogen moved in the crops each year is declining; and, ther, a considerable reduction of the nitrogen in e first 9 inches, with an indication of a small luction in the second 9 inches, is shown by different alyses of the soil itself.

The experimental plot to which I am about to refer eived for the first few years an application of ferent mineral manures and salts of ammonia, the

amount of nitrogen contained in these manures being considerably in excess of that removed in the straw and corn of the crops of wheat grown by them. In the season 1852, therefore, when purely mineral manures were used alone, the land was in a better position, as regards the exhaustion of its nitrogen, than that from which twelve crops had been removed since the application of manure.

From 1852 to the present time, potash, soda, magnesia, and superphosphate of lime have been applied every year. The application of potash and phosphoric acid each year has been more than twice as much as the largest crops of wheat could carry off; and as these substances suffer very little loss by drainage, there must have been a considerable accumulation in the soil during the twenty-eight years of their application. Dividing the twenty-eight years into four periods of seven years each, we find that over the first seven years the mineral-manured land gave a produce of 3 bushels of dressed corn, per acre per annum, in excess of the crop grown on the permanently unmanured land. During the second period of seven years the excess amounted to 2 bushels annually; during the third period it was 1½ bushel; and during the last period it was 1 bushel only more than the unmanured crop. The average produce over the whole period, calculated at 61 lbs. to the bushel, was, for the unmanured land, 12½ bushels, and for the minerals 14½ bushels

· acre. It is probable that some unexhausted idue of the nitrogen, applied before 1851, may ve been available for the crop grown by minerals ne during the early period; but even with this vantage, the amount of nitrogen removed in the duce of the mineral-manured crop, as given in . Gilbert's South Kensington lecture in 1876, s, on an average of twenty-five years, only 22·1 . per acre per annum, as against 19·3 lbs. taken in the unmanured produce during the same riod.

Under a most liberal supply of minerals, therefore, soil and atmosphere combined have been unable furnish 3 lbs. more of nitrogen to the crop, or to l to the produce more than 2 bushels of wheat r acre annually.

Analyses of the soil have not been made so freently upon the plot, manured with minerals only, upon the unmanured plot, but, as far as we can ge, the decline in the nitrogen is very similar in h cases.

My object in these pages is to trace out and lain the sources of natural fertility. I must, there-, refer those who wish to follow out the subject at re detail, to our article on "Twenty Years' Growth Wheat," published in the *Journal* of the Royal ricultural Society of 1864, which showed most clusively, that it only required an addition of some ible compound of nitrogen, to the minerals used

in the experiment upon which I have just been commenting, to raise the produce of wheat to the highest amount which the season was capable of growing. I may add that we are now within three years of a second period of twenty years, when a further report may be looked for, to confirm and strengthen the previous conclusions.

I have gone very fully into the evidence of the sources of fertility, and the character of the exhaustion shown by the experimental wheat field, because of the great national importance of wheat as a crop, and because the evidence which this field affords regarding the general exhaustion of the soil, and the character of such exhaustion, appears to be very clear and distinct. I propose to treat the results obtained in the other experimental fields much more briefly, and merely point out their general bearing upon the fertility of the soil, and the nature of the exhaustion.

PERMANENT BARLEY.

The land devoted to this crop last received an application of dung in 1847; since then one crop of wheat, one of clover, and 31 crops of barley have been removed. Only one series of analyses of the soil has been made, therefore at the present time we have no record of the changes which are going on.

There are several marked distinctions between wheat and barley; the former is sown in the winter, the latter in the spring; the former requires a firm

ɔact seed-bed, the latter, one of a light porous ɪcter; further, under the same conditions of ɪte, the crops may be differently affected, as was ɔase in 1880, when the wheat crop proved very ferent, while the barley crop was most abundant: ı, however, due allowance has been made for all distinctions, we find that the character of the ustion in the field under barley is very similar ıat in the field under wheat.

we compare the produce of the unmanured barley ıg the first and second periods of the experi- ;, we find that the reduction in the latter— ınting to 7 bushels of grain and 4 cwt. of straw ɪms one-third of the whole produce. On the which receives exactly the same liberal supply ıinerals as the corresponding wheat plot, there also been a decline of one-third in the crop, ınting to 10 bushels of barley and 5 cwt. of r per acre. While, therefore, both the unmanured the mineral-manured land has shown a propor- l decline, the application of the minerals has ıed the barley to produce annually, during the e period, 7 bushels more corn per acre than the which received no manure; this is considerably than the difference between the corresponding in the wheat experiments.

PERMANENT ROOTS.

The experiments in roots commenced in 1843, and since that time, either white turnips, swedes, sugar-beet, or mangels have been grown every year except three, when three unmanured crops of barley were taken in succession.

On account of the different kinds of roots grown, and especially from the clearly ascertained fact that the soil and climate at Rothamsted were more adapted to grow sugar-beet or mangels than turnips, it is impossible to show the character of the exhaustion of the soil by the same mode of illustration as in the case of the wheat and barley crops. If we were to take the produce, for the last ten years, of the sugar-beet or mangel grown on the unmanured land, or even on the land receiving a large supply of minerals, and compare it with the crop of turnips grown, during any ten years, under similar conditions, we should show increased instead of diminished produce, and any conclusion drawn from this fact with regard to the state of fertility of the soil would be erroneous.

We shall be able to form a better judgment as regards the question of the fertility of the soil from the fact that, during the last ten years, the highest amount of produce obtained by a very liberal supply of minerals annually, has only been a little over 8 tons per acre.

The season of 1880 was exceedingly favourable for roots; the general verdict of farmers was that the crop was one of unusual magnitude, and yet the produce by the mineral manures was less than 6 tons of mangels per acre. The analyses of these roots have not yet been made, but the nitrogen they contain will amount to about 17 lbs. per acre. This is almost identical with the amount of nitrogen which Dr. Gilbert, in his South Kensington lecture, states was taken off annually for ten years, between 1864 and 1875, by the wheat crop which received a similar application of mineral manures. With a liberal supply of nitrogen added to the minerals, the crop last year in one instance exceeded 30 tons.

We have made a considerable series of analyses of the soils of the various plots, and have arrived at the conclusion that the soil, from which the roots manured with minerals have been removed, is poorer in nitrogen than the soil similarly manured which grows wheat or barley. The broad leaves of the root plant are said to obtain large quantities of nitrogen from the atmosphere. At the present time, under a liberal supply of all the necessary minerals, about 15 lbs. of nitrogen to the acre is all that our roots can obtain from soil and atmosphere combined. With these facts before us, we may assume that the large crops of roots, grown in different parts of Great Britain by means of mineral superphosphate, are due to the

amount of available nitrogen existing in the soil during the growth of the crop.

In order to measure the exhausting effects of any agricultural crops, and also the special character of the exhaustion, it is not only essential that crops should be grown continuously, both without any manure, and with various manures applied to the same portion of land without change; but also that some of the manures applied should grow full agricultural crops. These conditions have not been fulfilled with either of the two crops to which I am now about to refer, viz., beans or red clover.

Since 1848 a field has been devoted to the growth of beans, but with very partial success. After a few years the unmanured produce was reduced almost to nothing, and with no combination of artificial manures could we succeed in producing agricultural crops.

Part of this want of success is due to the character of the plant—beans send down strong, fleshy roots into the subsoil, while much of the food we apply as manure is deposited on the surface, and finds its way very slowly to the subsoil, even if it reaches it at all. The value of beans, therefore, as a rotation crop depends very much upon the natural fertility of the subsoil. Beans are grown more or less in every part of Great Britain, but in most of the counties the area under this crop bears so small a proportion

to that under other crops, that evidently their more frequent cultivation does not pay, and the growth of the crop itself partakes somewhat of the nature of an experiment.

In a few localities, where large tracts of alluvial soil or rich clays are found, beans are grown with success; but only one or two of the counties in Scotland grow any quantity, and in those the alluvial soil extends over a considerable area. Although the soil of our bean field has been submitted to analysis, the results, from the want of success in growing the crop, do not show whether exhaustion is taking place or not.

In our attempts to grow red clover continuously upon our arable land, we have been even more unsuccessful than with the beans. The crop has been grown, however, for twenty-five years on an unmanured but very rich garden soil, and we find by analysis that there has been a very great reduction in the stock of nitrogen in the soil, in consequence of the amount of this substance which—as well as minerals—must have been carried off by the removal of the crops, during this long period. The result of this experiment leaves very little doubt that the inability of our ordinary arable land to grow red clover, is due to a want of sufficient food in the soil, and also to the want of its proper distribution.

It would hardly have been anticipated that the grain crops could thrive better, and get more food

from a permanently unmanured soil, than roots, clover, or beans, which are known to act as restorative crops. Such, however, is the case in the unmanured rotation which has been under experiment since 1848.

When the experiments were commenced the field devoted to rotation was in much better condition than either the experimental wheat or barley fields, and yet in a four-course rotation which included turnips, and clover or beans, alternating with wheat and barley, the evidence appears to show that a greater produce of grain would have been taken from the land by the continuous growth of cereals, without the alternation of restorative crops. The turnips after the first crop, when, as I mentioned, the land was in good condition, have ceased to be a crop at all, and with all the aid of the fine root-growing season of 1880, were incapable of forming a bulb. The average of six crops of beans was barely 13 bushels, and a red clover crop, taken after an interval of twenty-five years, was very small. The barley, however, has averaged 34 bushels, and the wheat 27 bushels, per acre during the whole period, and it is quite certain that if wheat had been grown continuously during the twenty-five years, it would have produced more than 14½ bushels every year; or if barley had been grown continuously it would have produced more than 17 bushels annually.

This property which our cereals possess of extra-

ing nourishment from a soil, where other crops are unable to do so, will be an important consideration when we come, later on, to estimate the exhaustion of the soil of those countries which compete with us in the growth of corn.

By the employment of a mineral superphosphate every four years the root crop has been largely increased, and when the roots have been carried off the land, the succeeding barley crop has been very much less than that grown upon the permanently unmanured land, where a very much smaller root crop was carried off over the whole period of the experiment.

The amount of nitrogen removed in the crops where the superphosphate was used, has been greater than that removed from the unmanured land, and the crops in both the experiments are declining; the analyses of the soil of the two experiments also show a decline in the nitrogen; but still we have no clear evidence to show upon which of the two experiments, the crop, or the nitrogen in the soil is declining the most rapidly. It would probably have been supposed that a period of thirty-two years would have been sufficient to establish a fact of this nature, but such has not been the case. There have been only eight rotations in the period, and each crop has therefore been grown only eight times. Owing to the great fluctuations in our climate these eight crops are not sufficient to measure with accuracy the rate of de-

cline, more especially as the last few seasons have been exceptionally unfavourable to the growth of corn.

I have already said that my permanent pasture contains a much larger proportion of nitrogen than the arable land. This excess probably amounts to more than 2000 lbs. per acre in the first 9 inches from the surface, without taking into account the great quantity stored up in the turf and roots. Under these circumstances we might expect that mineral manures would produce a more beneficial effect upon pasture than upon arable land, and such has proved to be the case, as, during the twenty-five years of experiment, the produce of hay grown by a liberal supply of alkalies and phosphate, has not only been very much greater than the produce obtained upon the permanently unmanured pasture land, but also, up to the present time, it has shown no perceptible decline. The grass is pale in colour, and shows none of the luxuriance and vigour which we find in the herbage where there has been an application of nitrogen, as well as of minerals; still the removal of about 46 tons of hay, containing more than 1000 lbs. of nitrogen, without any fresh application of that substance to the soil, is a very interesting fact.

No general analyses of the soil of these experiments took place until they had been carried on for twenty years; consequently, its composition when the experiments commenced is unknown. But a few selected

plots were analysed in 1870, and in 1875—the twentieth year from the commencement—several samples were taken to the depth of 54 inches on each experimental plot of the whole series.

The amount of nitrogen in the first 9 inches of the mineral-manured soil is found to be considerably lower than that in the unmanured soil. While, however, the hay removed annually from the unmanured land has not much exceeded 1 ton per acre, the hay removed from the mineral-manured land has amounted to rather more than $1\frac{3}{4}$ ton per acre.

To institute an exact comparison between the loss of the nitrogen in the soil of the mineral-manured and unmanured land, and the amount of nitrogen carried off in the two crops of hay, would only mislead, as it would be assuming the possibility of a minute accuracy in measuring the results, which, from the nature of the circumstances, would evidently be impossible.

I have now passed briefly in review the general bearing of the Rothamsted experiments, as regards the fertility and exhaustion of soils. Those who have taken the trouble to follow the results given in the preceding pages, can hardly fail to have noticed how very much the growth of our crops is dependent upon the stock of nitrogen stored up in our soils; and, as the crops and soil in other localities are, more or less, exposed to the same climatic influences as the crops and soil at Rothamsted, we may fairly conclude

that such crops are, in like manner, dependent for their growth upon the sources of fertility stored up in the soil.

I will not here pronounce an opinion with regard to the various ways by which the plant, or the soil may obtain nitrogen from the atmosphere; still, giving them all their full value, it cannot be denied that some of our crops have become much reduced for want of nitrogen, even where there was still a very considerable stock in the soil.

It would appear, therefore, that while our crops can obtain all the carbon they require from the atmosphere; for nitrogen, they are far more dependent than has generally been supposed, upon the stock which has been accumulated in the soil, or that which has been applied in manures.

Except at Rothamsted I am not aware that any attempts have been made to procure sufficiently representative samples of soil before they are submitted to analysis. The usual method has been, to take *about* a spadeful of soil, which has generally been considered a sufficiently accurate measure for the purpose. With us the process of taking the sample is quite as important an operation, and one requiring quite as much care and skill as that of making the analysis.

Although we generally take our samples in successive 9 inches, still we have occasionally taken them at each 3 inches in depth, and have found

t considerable differences exist in the quantity nitrogen as each 3 inches receded from the face.

A question then naturally arises as to whether the thamsted soil, as compared with other soils, is rich poor in nitrogen. It is hardly possible to omit all erence to this point, but at the same time, for the sons which I have given above, a very considerable rgin must be allowed for error, arising from the known depth at which some of the various samples ich I am about to bring forward for comparison y have been taken.

Professor Schmidt, of Dorpat University, has made very elaborate series of analyses of the celebrated ssian black soils, which are said to be the most tile in the world. These soils have also been alysed by Dr. Voelcker, for Mr. Butler Johnstone, o owned an estate in that part of Russia where y are found. There is a general agreement between two series of analyses; I have however adopted se of Professor Schmidt, as he gives the depth which his samples have been taken, and the nplings themselves have also been carried lower n in the subsoil.

n these analyses no attempt has been made to mate the average quantity of nitrogen per acre; ave therefore been left to the alternative of either ing the percentage of nitrogen in the soil—which veys no fact to a non-scientific reader — or of

adopting some estimate as a basis of the weight of the soil itself.

It would be a great mistake to suppose that these Russian black soils partake in any way of the character of the peat soils of Great Britain, which are very deficient in mineral matter. In Russia the surface of the black soil, richest in vegetable matter, contains also 84 per cent. of mineral matter; and usually the surface soil contains 90 per cent., and the subsoil from 90 to 97 per cent. of minerals.

I estimate that the richest soil in the series might contain, within 3 feet of the surface, from 40,000 to 44,000 lbs. of nitrogen per acre.

The Rothamsted pasture soil, within the same depth, contains from 10,000 to 11,000 lbs.; and the arable land from 8000 to 9000 lbs. of nitrogen to the acre.

Between 1 foot 10 inches and 2 feet 8 inches, the Russian soil contains more nitrogen than is contained in the surface soil of the Rothamsted pasture; and from six to seven times as much nitrogen as is contained in the Rothamsted soil at the above depth.

Another Russian soil, which was sampled at 9 inches from the surface, gives 10,700 lbs. of nitrogen per acre, while the second 10 inches give more than 4000 lbs.; but, below this depth, the amount of nitrogen is not greater than that found at the corresponding depth in the Rothamsted soil.

In one analysis it is stated that white chalk..

l at 14 feet from the surface; in another analysis
il, taken from arable land, the nitrogen in the
ce soil is not higher than that found in the
e land at Rothamsted. Whether this is due to
ıstion by cropping, or to the fact of its being
ally a less fertile soil, there is no evidence to
I may mention that all of the Russian soils
sed by Dr. Voelcker are exceedingly rich in
gen.

the *Journal* of the Royal Agricultural Society
368, Dr. Voelcker gives some analyses of soils,
from the arable land of a farm in the neighbour-
of Leighton Buzzard. The mean of the analyses
ro different samples of soil gave the amount of
lbs. of nitrogen to the acre in the first 18 inches
the surface; this would be about 3000 lbs. per
more than the nitrogen in the arable land, taken
ie same depth, at Rothamsted. Agriculturists
know the two districts would readily admit that
oils in the neighbourhood of Leighton Buzzard
l be more fertile than those of the district in
ı I live.

1858, Dr. Voelcker analysed samples of four
e soils from the State of Illinois, brought over
Ir. Caird, from whom I have ascertained that
fairly represent the character of the land to the
ı of 1 foot from the surface. To this depth they
l probably contain from 7000 to 10,000 lbs. of
gen per acre.

No one has devoted so many years to the analysis of soils as M. Boussingault, and I shall close this part of my subject by a reference to some analyses made by him.

His farm is situated at Bechelbronn, in Alsace, and he gives an analysis of the soil of a wheat field there, which resembles very closely in character that of the soil in my district. It is also somewhat remarkable that the same five-course rotation has been adopted both in Alsace and Hertfordshire, the only distinction being that in Alsace the three corn crops comprise two of wheat and one of oats, while in Hertfordshire, barley takes the place of the second wheat crop.

Boussingault gives the following amounts of nitrogen per acre, in various soils collected by him in different parts of the world, the calculation being made for a depth of 17 inches from the surface:—Argentan, rich pasture, 25,650 lbs.; Santarem, cocoa plantation, 32,450 lbs.; Rio Cupari, rich peat mould, 31,250 lbs.; Rio Madeira, sugar field, 5500 lbs. per acre.

In the early days of our experiments it was thought by some that the continuous growth of from 14 to 16 bushels per acre of wheat upon unmanured land was due to some unusual fertility in the Rothamsted soil. The evidence I have brought forward, however, so far from supporting this view, simply shows how little was then understood as regards the capacity of

an ordinary soil for growing continuous crops without any manure.

To sum up this part of the subject, it may be said that upon the land where continuous crops were grown without any manure, clover, beans, and roots, which are generally considered to restore the fertility to land exhausted by corn-growing, have declined more rapidly than the cereal grain crops; that a liberal supply of mineral manure, while it has added considerably to the produce of some of the crops, has not prevented their decline; that upon an unmanured four-course rotation, where all the produce is removed, the two crops of grain, grown in the rotation, do not give a larger produce than the continuous grain crops, grown during the same period on continuously unmanured land; that, in a rotation where mineral superphosphate of lime has been used, the root crop has been largely increased, and more nitrogen has been carried off in the produce than from the permanently unmanured rotation; but though the produce of both is declining, the evidence, up to the present time, is not sufficient to show on which of the two experiments this decline is proceeding the most rapidly. Lastly, that the general character of the analyses of the soils which have been made at different times, tends to confirm the conclusions just given, and to show a decline in the stock of nitrogen.

The experiments on pasture differ from those upon the arable land in the following important particu-

lars :—The produce of hay under a liberal supply of mineral manures has been greatly increased, and the amount of nitrogen removed has been very large; but at the end of twenty-five years there is no evidence of any decline in the produce.

It is true that the nitrogen in the surface soil of the pasture land shows a considerable decline, but with this exception there is nothing absolutely to prove that the atmosphere has not been the source of the nitrogen removed in the produce.

GREAT BRITAIN.

When we come to the application of the results given in the foregoing pages to the general agriculture of Great Britain, it is hardly possible to avoid the conclusion that, in most cases, profitable agriculture involves a slow but continuous exhaustion of the soil.

In the earliest stages of our agriculture, only the more fertile soils were cultivated; little, or none of the produce was returned to the land as manure, and long periods of rest intervened between one series of corn crops and another.

As population increased, land became more valuable, and the increasing wealth of the country enabled the people to consume a larger amount of animal food: the periods of rest were shortened, and fallow crops, such as roots and clover, were introduced.

In the production of meat, a very large proportion

of the soil-constituents of the food consumed by the animals would be returned to the land, and, in consequence of this restoration of fertility, there would be less exhaustion of the soil.

In certain districts of Great Britain there are soils so light, that they contain, in their original state, but a very small stock of natural fertility, and the crops they grow depend mainly upon that which is imported at the expense of the cultivator. There are also certain heavy soils which are very highly farmed; but, with these exceptions, it may be said of the existing system of agriculture in this country that, as regards relation of landlord and tenant, rent is paid for the right to remove, without restoration, a certain amount of the stock of fertility in the soil.

The various restrictions introduced into leases, covenants, and customs were evidently devised for the purpose of limiting, as much as possible, the removal of this stock of fertility; but from the complete ignorance which prevailed with regard to the ingredients of which it was made up, the restrictions were confined to such crops as experience seemed to show were especially exhausting to the soil.

If, as I have endeavoured to prove, the stock of nitrogen in our soils is one of the main sources of their fertility, the question arises—How are we to explain the benefits of the various operations of agriculture, such as draining, fallows, liming, tillage of all kinds, and the use of mineral manures, except by the

fact of their being so many means of liberating and utilising the stock of nitrogen in the soil?

Many of these operations are said to increase the stock of fertility; and that they do increase the *produce* of the land must be evident to the commonest observation; but it is at the expense of the stock in the soil; and they would be more correctly described as processes for turning to account the existing, but dormant elements of fertility contained in the land.

We may thus in a certain way compare the fertility of the soil, to the coal in a mine: neither the one nor the other is of any value until it is turned to some useful purpose, and this object cannot be attained without a diminution of the original stock. So much, indeed, is a reduction of this stock an essential to the profitable cultivation of many soils, that, if we could imagine a heavy clay to exist which did not supply any of the ingredients of plant food, it is doubtful whether its arable cultivation could be profitably carried out.

The natural fertility existing in a soil is cheaper than imported, or purchased fertility; and it would in fact be found more profitable to pay rent for a fertile heavy soil, than to farm unfertile heavy land rent free.

When a farmer increases his crops by means of such purchased manure as soot, or nitrate of soda, he estimates the profit of the operation by the increase of the crop alone. If his land would yield a crop of

.t worth £8 without the purchased manure, and ıe expenditure of 20s. the value of the crop was d to £10, he would consider the operation had ı him a profit of £1, as all the ordinary expenses .ected with the growth of the crop are charged ıst the produce derived from the natural fertility ıe soil.

ı the district where I live the land is cultivated five-course shift, and the crops which are grown, sold off the land, would cost more to produce by means of purchased artificial manures, than the which the tenant, under the above system of vation, pays for them in the rent; or in other ls, as far as regards the production of the crop, the owner sells his fertility cheaper than the manu- ırer of manure could supply it.

he employment of manure of some sort is uni- al in this country; and so far as such manure ists of ingredients derived from crops that have ı grown upon the farm, it retards and reduces amount of exhaustion. Large quantities of cattle s are also imported and used as manure; but large he amount of imported cattle food may appear, it be found that its consumption is confined to a paratively limited area, and that it has but little ıence on the general fertility of the country at e. As a proof of this fact I may say that the tion of only 1 lb. of nitrogen per acre to the 00,000 acres of cultivated land in Great

Britain, would require an import of about 500,000 tons of corn and cake, and the consumption of the country does not reach this amount. Even if the capital were forthcoming to carry out generally a system of high farming, a supply of purchased fertility, large enough to meet the increased demand, could not be obtained except at a price that would prohibit its use.

The evidence brought forward, in regard to fertility and exhaustion, enables us to comprehend somewhat more clearly the distinction between the fertility which is part and parcel of the soil, and that which is brought upon the land by the capital or the tenant.

There is still, however, before those who may be called upon to decide such questions, the very difficult task of ascertaining how much of any imported fertility still remains in the soil, and is available for future crops.

In the face of the increasing competition with the agriculture of the world, it is hopeless to bind the tenant's hands or cripple his energies by the restrictive covenants of a bygone age; and it would certainly be desirable, with the prospects of compulsory legislation on this subject, that the interests of both the landowner and the tenant should be more clearly defined.

If, at the commencement of occupancy, a brief agreement could be drawn up between landlord and tenant, to define the amount of fertility which the

tter was entitled to remove in exchange for his ent, the task of any arbitrator or judge, called in to ecide between conflicting claims, would be made ghter.

THE UNITED STATES.

We are sometimes told by enthusiasts, that a liberal plication of capital to the soil of Great Britain ould enable us to grow all the wheat necessary to ed our population; there cannot however be any ubt, that in the cheap production of grain crops, e United States farmer possesses advantages which ught not to be either overlooked or despised.

First of all, and this is a most important point, he United States farmer himself is usually well ducated and intelligent; he is both owner and occu- ier of the soil, and does as much as possible of the ork of the farm himself, employing for the purpose he most improved labour-saving machinery; he is ghtly taxed, has cheap modes of transit, and, above ll, is in possession of an almost unlimited extent of ntouched fertility. These circumstances all combined duce the cost of growing corn almost to a minimum, nd the result enables him to deliver his wheat at the oors of the owner of the land in some parts of Great ritain, cheaper than it can be raised in the adjoining elds. In a word, they enable him to regulate the rice of grain throughout the world.

In my remarks upon the agriculture of Great

Britain, while assuming that, with comparatively few exceptions, it is carried on by a process of soil-exhaustion, I have pointed out that this exhaustion is greatly lessened by the production of meat and the use of manure.

I propose now, for the sake of argument, to consider the agriculture of the United States as carried on without any part of the produce being returned to the land in the form of manure, though I am perfectly aware that such a system of farming only prevails in certain districts of the States. How great indeed is the interest taken in all questions relating to the action of manures, and the exhaustion of soils, is fully proved by the large space allotted to these subjects in the numerous journals devoted to agriculture, as also in the records of the various experimental stations. I may add that this inquiry into what may be termed the science of agriculture is in remarkable contrast with the comparative indifference to the subject which prevails in this country.

It is not however the corn grown in the United States by purchased fertility, or even by the manures made upon the farm, that the British farmer need fear, as likely to compete with him. The danger lies in the vast stores of unused fertility, which constitutes the main wealth of the United States; and this fertility, as I have already pointed out, is very much cheaper than any derived from artificial or imported sources.

In the table below, drawn up by me some years ago, from the reports of the Department of Agriculture at Washington, will be found the amount of land in the United States under various crops upon an average of ten years, viz. between 1865 and 1875. So great has been the increase of land brought into cultivation since that date, that in 1880, 31,000,000 acres of wheat and maize alone had been added to the existing area.

The table gives the number of acres, in millions and parts of a million, of crops grown in the United States, on an average of the above period of ten years; the produce per acre; and the number of acres per cent. of the various crops:—

	Acres in millions and parts of millions.	Yield in bushels per acre.	Acreage per cent.
Maize	37.21	26	40.4
Wheat	20.50	12	22.1
Rye	1.31	13½	1.44
Oats	9.75	28	10.5
Barley	1.15	22¾	1.25
Buckwheat	0.72	18⅓	0.78
Potatoes	1.25	93⅓	1.36
Hay	20.35	1¼ ton	23.1
	92.24		100.

It would appear, from this table, that the cereal grain crops were grown upon rather more than three-fourths of the arable soil in the States. Upon an equal area in Great Britain, 46 per cent. of the land is under grain crops, and though we have no

statistics of produce in this country, I am disposed to think that more corn is grown, upon an equal area per cent. of arable land, in the United States, than in great Britain; that is to say that 76 acres devoted to grain corps in America produce more bushels of grain than the 46 acres so employed in our country.

The superior power possessed by the gramineous, as compared with other plants, of obtaining food from an unmanured soil—which was very clearly shown in the Rothamsted experiments—is confirmed by the character of the crops grown in the United States, where not more than 2 per cent. of the whole cultivated soil is occupied by crops which belong entirely to other orders; while in the hay crop, which comprises a great variety of different species, it is probable that the gramineous herbage largely predominates, timothy being generally quoted as the hay sold in the various markets.

With regard to the amount of nitrogen removed from the soil of the States every year, assuming that no part of the produce is restored, I am disposed to think that it might amount to about 30 lbs., or possibly a little more, per acre annually; supposing always that the crops grown do not exceed the amount given in the table. It is however, I think, certain that soils newly brought into cultivation would for a considerable time grow very much larger crops than these.

The idea that the fertility of these soils must ortly come to an end, or that grain crops cannot be oduced at the present price, is altogether illusive. The stock of nitrogen in immense areas of the nited States soils must be competent to yield crops, ual to those given in the table, for a long time, and en when they begin to fall off, the residue of trogen may still be sufficient to allow of a fresh velopment of fertility by the employment of some eap mineral manure, such as plaster or phosphate lime; if this be so, the necessity of employing costly a substance as nitrogen may not be apparent r two or three generations yet to come.

Before this period arrives the United States farmer ill have become so well acquainted with the action manures, that the profit or loss attending their plication will not be a question of chance, but e subject only to the contingency of favourable or favourable seasons; a contingency from which it ll be impossible to escape.

INDIA.

It is hardly possible to conceive agriculture carried under conditions more completely different than se which exist in the United States and in India. Every new emigrant who lands upon the shores of United States is so much capital added to the lth of the country. The average size of the farms

held by each person, according to the census of 1870, is 153 acres, of which one half is still unimproved. With this large area at his disposal the United States farmer yet does not hesitate to give up his holding and seek a new home, if by so doing he thinks that he can better his condition.

In India the Hindu increases and multiplies upon the spot on which he was born, and regardless of all economic laws, is apparently endeavouring to solve a problem which has frequently perplexed political economists, as to the relative increase of population and food.

This is what Mr. Hunter says in his lecture recently delivered at Edinburgh, and since published under the title of 'England's Work in India.' "We find 24,000,000 of human beings struggling to live off the produce of 15,000,000 acres, or just over half an acre apiece." So vast is the area of India, and so limited are the modes of communication, that while in some districts there may be a superabundance of food, in others the people may be dying of starvation. Mr. Hunter says that "throughout all British India, the average population is 212 persons to the square mile; or deducting the comparatively new and outlying provinces of British Burmah and Assam, it is 243 persons to the square mile."

In the United States there does not appear to be more than nine persons to the square mile. The process however of comparing the population of

various countries with the relative area, although useful so far as regards the question of statistics, is very misleading when brought forward to show the capabilities of a soil to support its population. For instance, if we applied to the agriculture of Great Britain the conditions under which the agriculture of India is necessarily carried on, that is to say if we estimated how much of the products of the soil—irrespective of all external sources of food or fertility—would be required to feed, clothe, and furnish with fuel each inhabitant, we should require to make considerable modifications of existing ideas on the subject.

The Indian Famine Commissioners say that "there are considerable parts of India in which the population is so dense that it presses closely upon the means of subsistence; and here, unless the existing system of agriculture is improved so as to yield a larger produce per acre, there is no room for any increase."

The last famine is said to have reduced the population of India by 5,500,000. In a country where the struggle to live becomes greater each year, we can readily understand that the removal of a certain proportion of the population must be a source of increased wealth to the remainder; and the Commissioners refer to a despatch of the Secretary of State, dated February 28, 1880, in which it is said "the facts testify to the remarkable power of the agricultural classes to resist and recover from the effect of unfavourable seasons."

No one can read the report of the Famine Commission without being convinced that every effort was made, and no expense spared to mitigate the effects of the famine; still there can be little doubt that the population is in excess of the food-producing power of the soil; and that, within certain limits, the removal of a certain number must add to the well-being of the remainder. The recovery from the effects of the famine might however have been less rapid had the lives of the 5,500,000 people been saved.

The conclusions which I have drawn from the Rothamsted experiments, as regards the fertility and exhaustion of soils, do not tend to lessen the difficulties with which our rulers have to contend in providing for the increasing population of India.

In Great Britain, although a fertile soil has a higher agricultural value than one of less fertility, still the relative value is not in proportion to the different amounts of fertility which the two soils can respectively yield up to the crops. Fertility drawn from all parts of the world, as also the advantage possessed by light over heavier lands as regards the expense of cultivation and as producers of meat, tends to lessen the distinction which would otherwise exist.

In India no external sources of fertility are available, and meat is far too costly a food for the consumption of the tillers of the soil. We are told that forests are disappearing, pasture is being broken up, cow-

dung is used for fuel, and that the area of waste land, whence was derived much of the manure ingredients which help to keep up the fertility of the continually corn-cropped land, is becoming every year less and less. We have therefore the fact before us that the Indian farmer has to obtain his food, clothing, and fuel, and pay the tax to the Government, out of the soil he cultivates: further, that the fertility which grows his crops comes from the soil alone, without any aid from external sources.

The tax is assessed upon the estimated value of the crops which the land will yield, and we might therefore expect to find that the fertility of a soil was the real measure of its value.

This is what the Commissioners say on the subject: "In Bombay the assessment is carried out by a separate department, on a very ingenious and complicated system. The land is broken up into blocks of from 5 to 40 acres each, which are separately assessed. The soils are classified on a uniform system according to their depth, and their faults, such as sloping surface, liability to inundation, or having a mixture of sand, clay, or gravel in the soil, all of which are sources of deterioration. The field which bears a maximum value is a level one of black soil, deeper than 1¾ cubits: this is the standard, valued at 16 annas. Every 'fault' and every quarter-cubit's decrease in depth deducts one or two annas or sixteenths from the valuation."

A Hindu cubit is, I believe, 25 inches; to be of the maximum value the black soil must therefore descend lower than 3 feet 8 inches. At Rothamsted our ordinary samples of soil are taken at the depth of successive 9 inches, though in a few instances we have taken them at 3 inches, but the Indian assessor measures fertility in still less proportion than our smallest gauge, for one-sixteeenth of 3 feet 8 inches is very little more than 2½ inches.

In referring to the Russian soils I pointed out that, in one case, where the black soil went down to the depth of from 3 to 4 feet, the nitrogen in the subsoil was as high as it is in the surface soil of my pasture land; while in other cases, where the black soil did not go down so low, the subsoil was not very different from that at Rothamsted.

Assuming the highest-valued soil in Bombay to have the composition of the richest black Russian soil, the number of pounds of nitrogen per acre in the lower quarter-cubits would amount to about 160 lbs., while if the same area was taken in the districts where the black soil is not so deep, or upon the Rothamsted soil, the amount of nitrogen would be very much less.

With an absolute ignorance of all science, and merely by the experience derived from the growth of the crops, we have here an estimate of value placed upon every 2½ inches of soil to the depth of nearly 4 feet from the surface. Those who are disposed to ridicule

the idea of estimating the fertility of a soil by its stock of nitrogen will see how the value of such an estimate is confirmed by these results. It is true we have no analyses of these black Indian soils, but in the black Russian soils we have evidence, not only of their fertility, but also of the enormous stock of nitrogen which they contain, as also of the fact that the richness of nitrogen is limited to the depth of the black soil. The Bombay soil is celebrated for its fertility; who can doubt therefore that it has been, and probably still is, very rich in nitrogen?

With regard to the amount of exhaustion which is going on upon these Indian soils, it is by no means easy to form an estimate. According to Mr. Hunter, "Wheat land in the North-Western Provinces, which now gives only 840 lbs. an acre, yielded 1140 lbs. in the time of Akbar, and would be made to produce 1800 lbs. in East Norfolk." "Every one knows" (he also says) "that strictly scientific farming trebles the produce; that a field which produces 730 lbs. of wheat without manure can be made to yield 2342 lbs. by manure;" he further quotes the late Secretary to the Government of India in its department of Agriculture as declaring "that with proper manuring and proper tillage, every acre, broadly speaking, of land in the country can be made to yield 30, 50, or 70 per cent. more of every kind of crop than it at present produces; and with a fully corresponding increase of the profits of cultivation."

I have read Mr. Hunter's lecture with much pleasure, but trust he will forgive me for saying that had he been a little better acquainted with agriculture, he would not have made the comparison between the cultivation of the land as carried on in India, and in East Norfolk. The possibility of growing wheat crops with profit on the sandy soil of East Norfolk is due to the fact that a large amount of stock is kept in that district for which the farmer finds a ready sale at a high price, and to the facilities for procuring external sources of fertility, in the form of purchased cattle food and manure. Deprived of these advantages the Norfolk farmer would be more helpless than the Hindu.

Mr. Hunter feels some hesitation in adopting the statement of the late Secretary to the Government department of Agriculture, which I have quoted above, but believes that "without attempting any flights in scientific farming it is possible to steadily increase the Indian food supply to the extent of $1\frac{1}{2}$ per cent. per annum;" and he specifies four out of many considerations by which the produce of the soil may be increased. One of the impediments, he says, "to improved husbandry is the want of manure. If there were more stock there would be more manure."

Although stock necessarily produces manure, it by no means follows, under the peculiar condition of Indian agriculture, that an increase of stock would

increase the supply of human food. If in addition to his corn-bearing land, the Hindu had a considerable tract of waste land, where the animals could pick up a means of subsistence in the day, which would enable them to furnish milk and manure, the advantage would be obvious; but in those districts where dung is used as fuel, where one person has to get his living from an acre of land—which area includes swamps and waste—and in other districts where half an acre has to support an individual, it would probably be necessary to devote every inch of ground to the production of food for the family, and the consumption by stock of any part of the very limited supply might just make the difference between bare existence and starvation.

From a table given in the report of the Famine Commission it would appear probable that there is about nine-tenths of an acre in food crops to each head of the population, the other tenth being in what are described as non-food crops, such as indigo, cotton, hemp, tobacco, &c. The land yields about 10 bushels of corn per acre, principally millet or rice, 8 bushels of which are consumed, three-quarters of a bushel is used as seed, a rather less quantity as cattle food, 31 lbs. are allowed for waste, and rather more than 1 bushel is sold. The value of the produce raised is less than £2 per acre, upon which about 2s. per acre is paid as a tax to the Government.

With regard to the exhaustion of the Indian soils,

there can be little doubt that some decline in fertility is taking place ; also that, as population increases and more of the waste land is broken up and converted into tillage, this exhaustion will go on in an increasing ratio ; and however valuable irrigation may be as a means of bringing into action the resources of the soil, it must not be forgotten that unless the water contains the elements of fertility, either dissolved or suspended, it tends to diminish rather than increase the fertility contained in the soil.

It is true, no doubt, that where 1000 lbs. of grain are produced on an acre of land, and the bulk of this amount is consumed by the cultivator, the manure from both the corn and straw would for the most part find its way back to the land ; and even assuming that no external manures were derived from waste lands, this would so far reduce the exhaustion as to make the decline of the crop upon moderately fertile soils hardly perceptible, unless when taken over very lengthened periods of time. Still there must be exhaustion of the nitrogen of the soil, more especially in cases where we know that not only is the dung used as fuel, but also that saltpetre is manufactured from the drainage coming from the houses.

It would appear that the Indian cultivator has learnt how to extract the greatest possible amount of produce out of his soil, and neither the Norfolk farmer nor the scientific agriculturist—if restricted to such means as alone are available—could aid him

to produce better results. If however the Hindu could be taught that, while the demands upon the soil are increasing year by year, the produce of the soil, if not decreasing, is certainly not increasing, he will have learnt one important lesson which materially affects his welfare.

IRELAND.

When Ireland suffers from a deficiency of food, or from famine, the causes may be traced to the action of the climate, much in the same way as a similar cause produces a like effect in India. In each country the peculiar characteristics of the climate are occasionally intensified; excessive heat and drought produce famine in India; while too much moisture, combined with an absence of sunlight, produces scarcity and famine in Ireland.

In Great Britain, the United States, and in India, the cereal grains constitute the staple food of the population; while in Ireland potatoes are the main article of food.

Although the potato possesses in common with the cereal grain crops the property of producing large quantities of starch, it differs from them in several important points; it belongs to a different botanical order of plants, the starch is mainly stored up in its tubers instead of in the seed, and its growth extends all through the summer into the autumn, long after the ordinary cereal crops are harvested. The potato is

thus enabled to take up food from the soil at a period of the year when some of the more important manure ingredients are produced in the greatest abundance. The only cereal crop at all to be compared with it is maize, which likewise extends its growth into the autumn, and this probably is one of the reasons why the yield of maize in the United States is so much higher than the yield of the other cereal crops.

The potato further possesses the property of converting a very much larger portion of the manure ingredients of the soil into human food, than any of the cereal grain crops: for instance, to every bushel of wheat about 100 lbs. of straw are grown, while the haulm of the potato when dry is so light, that in our experiments we frequently do not think it worth while to weigh it. These properties, when combined with a suitable climate, enable the cultivator to produce, upon a given area of ground, a larger amount of human food from the potato than from any of the cereal grain crops.

In connection with these advantages, the potato, on the other hand, possesses the terrible disadvantage of being subject to disease to an extent unknown as regards the cereals.

Since 1848 statistics have been collected in Ireland which furnish us not only with the acreage under the various crops, but also with the average yield of each.

It will be interesting to examine these statistics for

: purpose of ascertaining whether they show any ference in the yield which might be attributed to decline in the fertility of the soil. The statistics only available from 1849, which would include a riod of thirty-two years; as however the figures · 1880 are not yet published, and the favourable ps of that year would have tended to neutralise bad crops of 1879, I have thought it fairer to lude 1879 from the table and take the two periods ifteen years, commencing with 1849 and ending '8. The crops I have selected for examination are , potatoes, and flax; the results will be found in following table:

LE.—*Showing the acreage, and average produce per acre, of ts, potatoes, and flax, on the average of two periods of fifteen ears.*

	Oats.		Potatoes.		Flax.	
	Acreage.	Average yield.	Acreage.	Average yield.	Acreage.	Average yield.
		cwt.		tons.		stone, 14 lbs.
ge:						
3 . .	2,058,544	12.96	1,011,214	4.15	128,309	33.01
9 . .	1,605,867	12.74	974,372	3.32	178,981	25.87
ent. reon dur- second d.	22	1.5	3.6	20	+39.5	21.6

n oats there has been a steady and continuous line in the acreage grown in each period of five rs from the commencement, while the average d of the last fifteen years is only $1\frac{1}{2}$ per cent. less

than that of the first period. In potatoes, the acreage grown is only slightly lower in the second period; there is, however, a very serious decline in the yield of the crop, amounting to 20 per cent., in the last fifteen years. In flax the acreage has been subject to some remarkable changes. Commencing in 1849 with 60,314 acres, it increased, with some slight interruptions, until it arrived at over 300,000 acres in 1864, but from that period it has steadily declined still, the latter half of the thirty years shows an increase of acreage of 39½ per cent. over the first half. The decline in the yield of flax in the second period is very similar to the decline in the potatoes, amounting to 21½ per cent.

In two out of the three crops, we have a decline in the acreage during the latter period, while in all three there is also a decline in the yield per acre; the decline is very slight in the oats, but very considerable in the potatoes and flax. So far as the decline is due to exhaustion of the soil, we should expect to see it more marked in the potato and flax crops than in the oats, for, as I have already pointed out, the cereals, as compared with other crops, have a greater capacity for extracting food from an impoverished soil. The decline in the yield of the potato is accompanied with a decline in the area under cultivation; it cannot therefore be said that, owing to the increase in population, or some other causes, the cultivator has been compelled to extend his operations to soils having

lower degree of fertility; the decline can only be ascribed to one of two causes, viz.: unfavourable seasons, or exhaustion of the soil.

The influence of weather upon the produce of the soil is one of the most complicated problems with which we have to deal: with regard to the seasons, each as compared with another has its own particular character, which is more or less favourable to the different crops that are grown.

In England, the year 1880 was very unfavourable to the wheat crop, while highly favourable both for barley and roots. If we were dealing with the wheat crop alone, so far as England is concerned, there would be very little doubt that a larger number of unfavourable seasons have occurred during the last period of fifteen years; but in Ireland, as regards the wheat crop, though there is a decline in the latter period, still, as it altogether does not amount to 5 per cent. the seasons can hardly be considered to have been specially unfavourable even to the growth of wheat, and the statistics for Ireland show no decline in the hay crop, and but a very small decline in the oat or barley crops, during the last period as compared with the first.

The large decline in flax and potatoes is exactly what we should expect to find if these two crops had been grown upon unmanured, or badly manured soils. While however a decline in the yield of potatoes might be looked for upon an impoverished soil, it by no

means follows that the produce would be more liable to disease. On the contrary, our experiments show that it is the highly manured potatoes which suffer the most from disease, and I think that the evidence given before the Potato Committee, by those engaged in the growth of this crop on a large scale, points to a similar conclusion.

While allowing therefore for a difference in seasons between the two periods, and that such difference is in favour of the former period, I am still disposed to think that the statistics indicate a certain decline of fertility in the soils of Ireland; and looking at the general character of the Irish soils, as well as the nature of the crops grown, this exhaustion might very probably be due to the removal from the soil of minerals, rather than of nitrogen.

CONCLUSION.

I will now proceed to sum up, and in some degree strengthen the evidence I have brought forward in the preceding pages in support of the views I have advanced with regard to the fertility and exhaustion of soils.

The Rothamsted experiments, at the present stage of their progress, indicate much more clearly than has hitherto been done, the line between the influence of the soil, and that of the atmosphere, in contributing the materials of which our crops are composed.

While I do not deny that plants may take up some carbon from the soil, and that they, or the soils in which they grow, obtain some combined nitrogen from atmospheric sources, still the results of the Rothamsted experiments relating to the chemical statistics of agricultural production, clearly show that the atmosphere is the main, if not the exclusive source of the carbon of our crops, and that the soil is the main, if not the exclusive source of their nitrogen.

With regard to the nitrogen, I would ask the following questions:—Is it possible by means of any crops, of any mechanical operations, or of any manures not containing nitrogen, to carry off more of the substance in the crops than is contained in the soil? And further, as the application of nitrogen by means of cattle-foods or manures is always attended by some loss—Can *as much* be recovered in the crops, as the sum of the amount brought on, and of that already existing in the soil?

The views of M. Georges Ville upon the subject of the sources of the nitrogen of our crops, as given in his book on "Artificial Manures," translated by Mr. Crookes, may be summed up as follows:—That crops always yield more nitrogen than is supplied in the manure; and that this excess is derived, not from the soil, but from the atmosphere. He points out, how small is the amount of combined nitrogen existing in the air as ammonia and nitric acid; that crops cannot

get more than about $5\frac{1}{4}$ lbs. of combined nitrogen per acre annually by rain; and that hence the source must be the free nitrogen of the air. He concludes— that leguminous plants, such as peas, beans, clover, trefoil, and lucerne, take practically the whole of their nitrogen from the air;—that others, such as beetroot and colza, require a certain amount to be supplied by manure, in order to establish active growth, but that after this they draw their supplies from the atmosphere; lastly, that others, such as the cereals, require the chief of their supply to be provided within the soil.

It will be observed that the facts I have adduced, and the conclusions I have drawn from them, are quite inconsistent with those put forward by M. Ville; and more especially those relating to the sources of the nitrogen of the leguminous and root crops.

I maintain that the amount of nitrogen supplied to our crops from the atmosphere,—whether as combined nitrogen brought down by rain, or that absorbed by the soil, or the plant,—constitutes but a very small proportion of the total amount they assimilate; and that the soil itself (or manure) is practically the main source of their supply. Indeed, it is a question whether, on arable land, as much or more may not be lost by drainage, or otherwise, than is supplied by the atmosphere.

It is not in the difference of their capacity for

taking up nitrogen from the atmosphere that we must look for an explanation of the distinctive influence, or function, so to speak, of the crops grown in a rotation. The explanation is rather to be found in the difference in the character and length of life of the different plants; in the character of the roots in regard to number, range, size, &c., and to their aptitude to derive more of their food and moisture from the surface, or from the subsoil; finally in the greater capacity of some for liberating and assimilating food not available to others, or for arresting food which would otherwise be washed out of the soil.

It will perhaps be said, that in maintaining the soil to be practically the source of the nitrogen in our crops—the leguminosæ and root crops as well as the cereals—we do away with the chief value derived from a rotation, viz. that of restoring fertility to the soil.

I admit that as a leguminous carries off much more nitrogen than a cereal crop, it is impossible to escape from the conclusion that the soil will be poorer in nitrogen after the removal of a leguminous than of a cereal crop. It is also a well-established fact, that a larger crop of wheat will be obtained after clover, which has removed a great deal of nitrogen, than after wheat, which has removed much less.

But the farmer has found by experience, and we have proved by direct experiment, that the roots, and other nitrogenous residue of a clover crop, may be

sufficient to supply all the nitrogen required by the succeeding corn crop. Indeed, it would appear from analyses that the surface soil of ordinary arable land may gain much *more* nitrogen by the growth of a clover crop than is required by the succeeding cereal crop. It may also be here observed, that the increase of 1 qr. of wheat and its straw, by the intervention of a clover crop, only represents an increased yield of nitrogen of some 12 to 14 lbs.

In the case of soils poor in accumulated or available nitrogen, the growth, and the after effect, of a clover or other leguminous crop, is less than in soils richer in available nitrogen.

In illustration of this fact, I may mention that in 1850 we took a crop of red clover from our continuously unmanured rotation experiment, and after an interval of twenty-four years, when we repeated the crop, the produce only amounted to about 1½ ton of hay, while the immediately succeeding wheat crop was even less than that obtained on a corresponding plot which had been under bare fallow instead of clover. In fact, taking the total six crops since the removal of the clover in 1874 (wheat, swedes, barley, beans, wheat, and swedes), the total amount of nitrogen removed from the unmanured clover plot, and from the unmanured fallow plot, was almost identical.

On the other hand, when a mixed manure, containing a liberal supply of nitrogen, had been applied, once every four years since the commencement of the

periment, not only was the amount of clover hay, also the amount of nitrogen removed in it, nearly ree times as much as that on the unmanured plots, t the crops succeeding the removal of the heavy ›ver crops have been heavier, and have contained ›re nitrogen, than those from the similarly manured ›t which was left fallow instead of being sown with ›ver.

Whatever may be the explanation of the well-:ablished fact that, in ordinary agriculture, a wheat ›p succeeding clover finds a more liberal supply of :rogen in the soil available for its use, than where succeeds another corn crop, the fact itself cannot, due consideration of the various illustrations which ve been given, be taken as any argument in favour the assumption that the nitrogen of the clover crop ıs derived from the atmosphere.

The farmer only sees that there is an immediate neficial effect produced on his wheat crop by the evious growth of clover; while science has estab-hed, that this is connected with an increased avail-le supply of nitrogen in the soil for the wheat ɔp. But in these facts themselves, there is no idence whatever whether the nitrogen of the clover ›p was derived from the atmosphere or from the l.

Nor can the United States farmer, who by the use ;ypsum so largely increases his clover, as also the eat crop which succeeds it, tell (any more than the

English farmer) from these facts, whether he has increased, or reduced, by from 100 lbs. to 200 lbs., the stock of many thousands of pounds of nitrogen which an acre of his soil contains within the range of the roots of the crops.

If we consider the well-established characteristics of the various leguminous crops grown in rotation, and the circumstances of their growth, it will be seen that their powers of taking up nitrogen, and of contributing to the increased growth of succeeding crops, are much in proportion to the length of their lives, and the range of their roots. Thus, everyone will admit that lucerne, sainfoin, and red clover, will grow larger crops without manure, and will leave a larger residue for the growth of succeeding crops, than either white clover or tares.

Again, if we follow the course of a barley and of a red clover crop, both sown nearly at the same time, it will be seen that when the barley has ripened its seed, the active growth of the clover has scarcely commenced, and the plant has still the latter part of the summer, the whole of the autumn, and to the autumn of the succeeding year, to collect its food. A man would consider himself very unfairly handicapped if he were required to do as much work in four months, as another was allowed eighteen months in which to perform it. After the cessation of the life of the barley, the formation of nitric acid in the soil is doubtless still active. In fact, direct

xperiments show that the autumn drainage removes nore nitrates than that of other periods of the 'ear.

It is doubtless one of the economic functions of the lover plant to arrest and store up the nitrogen of he nitric acid in the soil, which would otherwise e drained away during the autumn and winter. Vhether or not the leguminosæ may further take up ny of their nitrogen directly from the nitrogenous rganic matter within the soil, there is no direct evidence to show, though there are some facts which might be held to lend probability to the assumption.

When we see that the appearance of a fungus even on very poor grass land, is always accompanied by a rich growth of grass, we conclude that it has the property of liberating and utilising nitrogenous compounds in the soil which the grasses were unable of themselves to turn to account. It is at any rate not impossible that the leguminosæ may likewise derive at east a portion of their nitrogen from nitrogenous rganic compounds within the soil; but their possession f green leaves may be taken as evidence that they erive the chief of their carbon from other sources han the organic carbon of the soil.

It is true that there are some known circumstances connection with the growth of the leguminosæ hich are not inconsistent with the idea that they erive their nitrogen from the atmosphere; and, if hat view could be established as a fact, these cir-

cumstances would certainly receive a convenient explanation. Among them may be mentioned—the general indifference of such plants to a direct supply of nitrogen by manure; the benefit which they sometimes derive from the application of purely mineral manures; the increased amount of nitrogen in the surface soil after their growth; and the increased growth which they thus give to succeeding cereal crops.

But, on the other hand, the view in question entirely fails to explain—why those leguminous crops which take up the most nitrogen can be less frequently grown on the same soil; why we have entirely failed to grow clover successively on ordinary arable land, which was nevertheless in condition to yield fairly good corn crops; why the only condition under which we have been able to grow clover continuously, was where the soil was very much richer in nitrogen, as well as in other constituents, than the arable land; and lastly, why the growth under such circumstances has been accompanied by a rapid diminution in the amount of nitrogen in the soil.

It is quite true, that we have not been able clearly to establish by analysis that the subsoil of ordinary arable land, which has grown clover, is poorer in nitrogen than that of land which has been continuously under corn. When however we consider—that an acre of the Rothamsted arable soil taken to a depth of about 4 feet 6 inches contains about

,000 lbs. of nitrogen; that different samples of bsoil from the same plot will vary somewhat from e another in their percentage of nitrogen; that only m 100 to 200 grains are submitted to analysis; d above all, that we can only repeat the growth of ese deep-rooted crops at intervals of from eight to elve years, it will be obvious, that to obtain abso-tely certain experimental evidence on the point is, to y the least, extremely difficult.

It is, indeed, fortunate for agriculture, and also me consolation for the difficulties thus introduced to investigation, that the stock of nitrogen, even in comparatively poor subsoil, is large enough to nder the measurement of the losses to which it may subject, only possible when the experiments are rried on over a very long series of years.

If the evidence of the Rothamsted experiments up the present time has not established, beyond all il, that practically the source of the whole of the rogen in our crops is the store within the soil elf, and the nitrogenous manures brought upon there can be little doubt that in the course of their ure progress they will afford conclusive evidence on s point.

At Rothamsted there are about twelve acres of land, tributed in six different fields, and under more than many different crops, which have either been kept tirely without manure, or have only received purely neral manures, for periods of from twenty-five to

forty years. As these areas are exposed to the same atmospheric influences as other fields, and as the crops growing on them are, with the one exception that they receive no nitrogen by manure, subject to the same influences as similar crops in neighbouring fields, we may look with confidence to the results which they will yield in the course of time.

If we cannot hope to live long enough to reap the harvest, ours at least has been the satisfaction of having sown the seed, and watched over the progress of the crop which will ultimately yield it.

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ON THE

AMOUNT AND COMPOSITION

OF THE

RAIN AND DRAINAGE-WATERS

COLLECTED AT

ROTHAMSTED.

BY

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AND

R. WARINGTON, F.C.S.

WITH APPENDIX TABLES.

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INTRODUCTION.

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INTRODUCTION.

is proposed to collect together in the present paper the ults of all the investigations relating to the Rain and ainage-waters of Rothamsted. A part of these investigations s been already published—as the determinations of Ammonia Rain, communicated to the British Association in 1854; e determinations of Ammonia and Nitric Acid in Rain by of. Way, published in the 'Journal of the Royal Agricultural ciety' in 1857; the numerous analyses of the Rain and rainage-waters by Dr. Frankland, published in the Sixth eport of the Rivers' Pollution Commission, 1874; and the alyses of the Drainage-waters published by Dr. Voelcker in e 'Journal of the Royal Agricultural Society' in 1874. Some of ese results are inaccessible to most readers; many of them we ve never yet had an opportunity of discussing fully.* Having erefore a considerable amount of new matter to bring forward, has seemed best to treat the subject as a whole, and to discuss concisely as possible the relation of all the facts hitherto certained, bringing the record down to the present time.

The subject will divide itself into Four Parts. The FIRST RT will treat of the amount and composition of the Rainfall. he SECOND PART will embrace the results relating to Drainage d Evaporation from unmanured and uncropped land. The IRD PART will deal with the Drainage-waters from land nured and cropped. In the FOURTH PART we shall endeavour apply some of the facts previously given to the elucidation

* Some of the bearings of these earlier investigations have been already ited out in Rothamsted Reports, which have appeared in the 'Journal of Royal Agricultural Society.' See papers on the 'Effects of the Drought of 0 on some of the Experimental Crops at Rothamsted,' 1871; 'Report of Expeents on the Growth of Barley for Twenty Years in succession on the same d,' 1873, pp. 367–372; 'Our Climate and our Wheat Crops,' 1880, pp. 199–210.

B

of certain agricultural problems. In each section of the subject we hope to find space for a brief glance at some of the results obtained by others in the same field of inquiry.

PART I.—THE AMOUNT AND COMPOSITION OF THE RAINFALL.

1. *The Rain-gauges.*

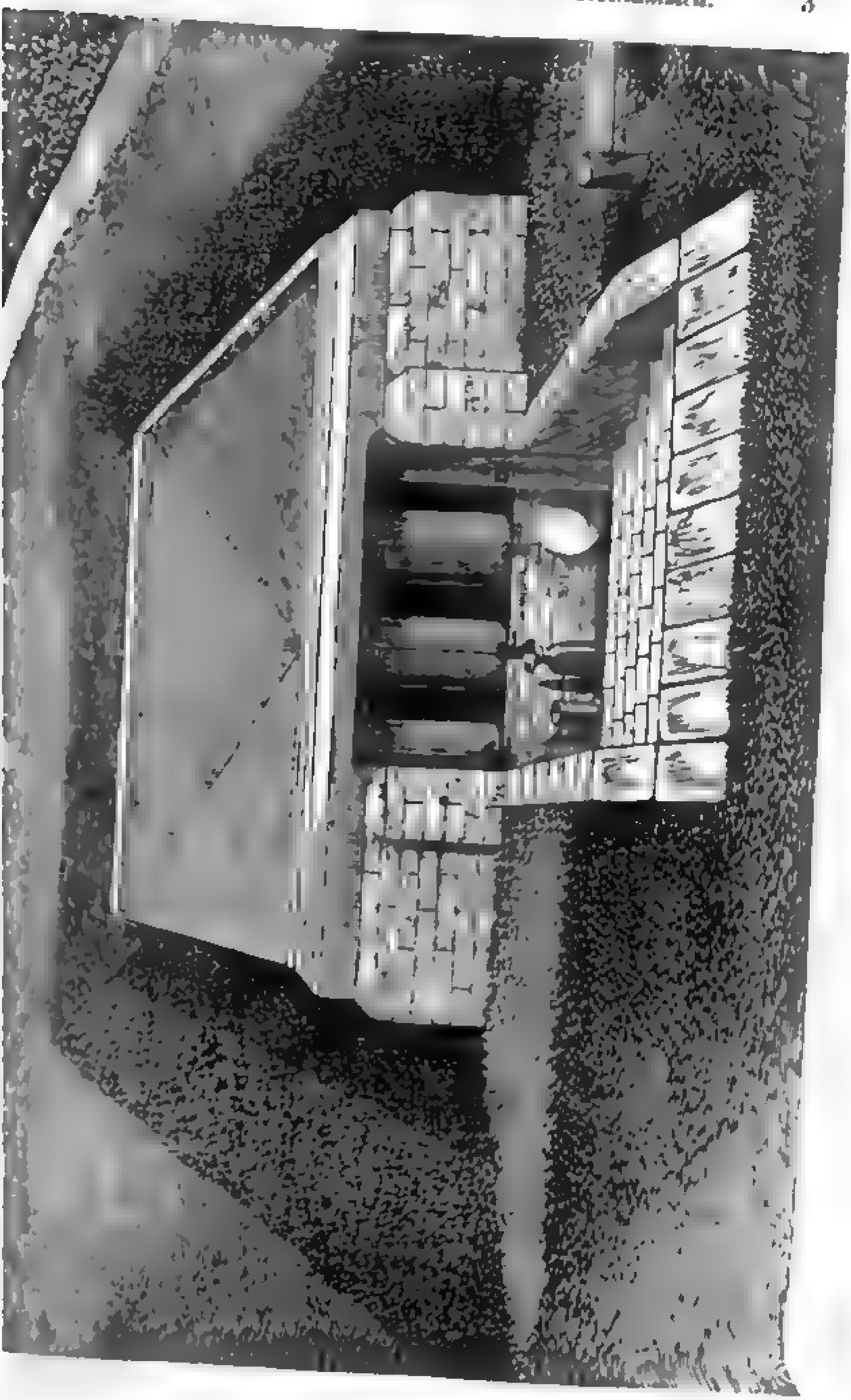
With the purpose of determining accurately the amount of the rainfall, and at the same time of collecting rain in sufficient quantity to allow of its chemical analysis, a large Rain-gauge was erected during the winter of 1852–3 in one of the arable fields on the farm at Rothamsted. The collecting funnel was of wood lined with lead. Its form was rectangular; the length 7 feet 3·12 inches, the width 6 feet. It had therefore an area of $\frac{1}{1000}$ of an acre. The surface of the funnel was 2 feet above the level of the surrounding ground, and 420 feet above the level of the sea.

The water collected in this funnel was received by a glass carboy standing beneath it. This carboy when nearly full overflowed through a pipe in the neck into a second carboy in connection with it. The quantity of water collected was, when necessary, ascertained twice a day by weighing the carboys. One inch of rain falling on this gauge would furnish 226¼ lbs. of water.

This gauge was in constant use from February 1853 to November 1876. Latterly, that is since August 1873, the use of carboys was discontinued, the water being received in galvanised iron cylinders fitted with gauge-tubes, and its quantity determined by measurement instead of by weight.

The large gauge just described has now been replaced by another of identical form and area, erected in the immediate neighbourhood of the old gauge. The land on three sides of the new gauge is not now under tillage, having been laid down in grass in 1874. On the remaining side is a field continuously cropped with roots. The edge of the collecting funnel of the new gauge is constructed of plate-glass, the remainder of the gauge being, as before, of lead. The edge of the funnel is about 1 foot above the level of the surrounding soil.

The water from the new gauge is received in a galvanised iron cylinder placed beneath; this when nearly full overflows into a similar cylinder standing at its side, which in its turn overflows into a third, and that into a fourth. Each cylinder will contain rather more than half an inch of rainfall, and is provided with a graduated gauge-tube by means of which the rainfall can be ascertained to $\frac{1}{1000}$ of an inch. A sketch of this rain-gauge will be found in Fig. 1 (p. 3). Its [illegible]



in July 1873, and has been continued down to the present time.

Besides the two large gauges just described, an ordinary rain-gauge, consisting of a circular copper funnel 5 inches in diameter, delivering into a bottle enclosed in a metal cylinder, has been continuously employed, and its readings recorded. This gauge was at first placed by the side of the first large gauge, and at the same elevation above the ground; it has since been moved to the side of the second large gauge, and brought to its level.

2. *The Amount of the Rainfall.*

The total rainfall recorded by the first and second large gauges during the first year of their comparison was practically identical, the old gauge showing a rainfall of 22·361 inches, and the new gauge a rainfall of 22·363 inches. A considerable difference afterwards appeared between them, arising apparently from leakage in the old gauge, which had also altered somewhat in form from the warping of the wooden framework. The use of the old gauge was therefore finally discontinued.

The small gauge has shown, on an average, a distinctly smaller rainfall than the large gauges. Taking a mean of 28 years (1853–80), the large and small gauges compare as follows:—

TABLE I.—COMPARISON of the LARGE and SMALL RAIN GAUGES (MEAN of 28 YEARS).

	Mean Monthly Rainfall.		Deficiency of Small Gauge.	
	Large Gauges.	Small Gauge.	Actual.	Per cent.
	Inches.	Inches.	Inches.	Inches.
January	2·590	2·263	0·327	12·6
February	1·728	1·508	0·220	12·7
March	1·693	1·399	0·294	17·4
April	2·008	1·803	0·205	10·2
May	2·329	2·149	0·180	7·7
June	2·451	2·272	0·179	7·3
July	2·704	2·533	0·171	6·3
August	2·643	2·440	0·203	7·7
September	2·638	2·403	0·235	8·9
October	3·089	2·784	0·305	9·9
November	2·345	2·113	0·232	9·9
December	2·084	1·861	0·223	10·7
Total for Year ..	28·302	25·528	2·774	9·8

It is seen that the small gauge agrees best with the large gauges in the summer months, and that on either side of July the difference between them gradually increases. The largest difference occurs in March, but in all the winter months the variation is considerable. On the whole year the small gauge

ows, on an average, 2·774 inches less rain than the large uges, or a deficiency of 9·8 per cent.

Some of the causes contributing to this difference between the uges are tolerably manifest. Thus a heavy snow-fall is much tter retained by the large gauge than by the small; the posits of mist, dew, and hoar-frost are also distinctly greater ith the large gauge. The increased difference between the uges during the winter months thus admits of explanation, hile the difference observed during the middle of summer is ot so easily accounted for.

The rainfall at Rothamsted for each month and year during e twenty-eight years 1853–80 is given in Table II. The infall for January 1853 is adopted from the records at hiswick, the Rothamsted gauge being not then completed. rom February 1853 to the end of June 1873 the results given re those obtained with the first large gauge. From this date to e end of 1874 the results are the mean of those yielded by the rst and second large gauge. After this date the rainfall is that easured by the second large gauge. For certain days on which portion of the rainfall was lost the readings of the small gauge ve been adopted. For two months, distinguished by brackets the Table, an estimate has been made of the probable rain or ow on certain days, no certain record being obtained.

The average rainfall at Rothamsted during twenty-eight ars has been 28·302 inches. This rainfall is distinctly gher than that usual in the eastern counties of England. In e excellent Hyetographical Map, prepared by Mr. G. J. mons for the Sixth Report of the Rivers' Pollution Comission, it appears that while the rainfall of the eastern counties generally below 25 inches, the rainfall of an isolated district mprising part of Hertfordshire, Buckinghamshire, and a all portion of Bedfordshire, is between 25 and 30 inches. It in this district of relatively high rainfall that Rothamsted is uated.

We have been kindly supplied with copies of the records of infall at various stations, situated mostly in the neighbourhood Rothamsted, those stations being selected at which observans had been made throughout the twenty-seven years, 1853–79. e are indebted to the Rev. C. W. Harvey for copies of the cords at Gorhambury, St. Albans; Nash Mills, Hemel empstead; and Hitchin: to Mr. J. M'Laren for the record of s own observations at Cardington, Bedford; and to Mr. G. J. ymons for copies of the records at Royston, and at Stretham, ly. To compare with these we have also taken the records of reenwich rainfall, as given by Mr. W. C. Nash in Symons' British Rainfall, 1879.' In the following Table these rainfall-

TABLE II.—MONTHLY and YEARLY RAINFALL at ROTHAMSTED during 28 YEARS, 1853 to 1880 (Large Gauges).

YEARS.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total 12 Months.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1853	2·020	1·309	2·363	2·999	1·682	3·395	4·181	2·978	2·011	3·659	2·052	0·108	29·360
1854	2·034	0·919	0·514	0·198	4·384	0·763	1·051	2·824	0·779	2·289	1·531	1·760	19·376
1855	0·598	0·993	2·364	0·410	2·324	1·617	6·956	2·633	1·515	5·501	2·473	1·722	29·166
1856	2·782	1·352	1·004	2·611	4·707	1·912	1·484	2·615	2·187	2·871	1·122	2·235	27·215
1857	3·708	0·570	1·484	2·161	1·105	2·215	1·611	3·077	4·172	5·910	2·247	0·579	28·842
1858	0·970	1·429	0·801	2·583	2·553	0·958	3·186	1·561	1·537	1·600	0·876	1·986	20·040
1859	1·339	2·014	1·729	2·704	2·132	3·409	3·021	2·778	3·436	2·861	2·284	2·792	30·499
1860	3·425	1·221	2·026	1·941	4·302	6·256	2·033	4·223	2·768	1·767	2·455	1·430	33·847
1861	0·813	2·415	2·286	1·276	1·045	2·976	3·190	0·887	1·633	1·403	3·993	1·578	23·555
1862	1·773	0·599	3·061	2·838	2·914	3·407	1·798	2·504	2·289	4·052	1·345	1·736	28·316
1863	4·037	0·744	0·913	0·960	1·011	4·601	0·703	2·866	2·907	2·319	2·217	1·639	24·950
1864	1·283	0·771	2·475	1·248	1·880	1·786	0·894	0·775	3·136	1·292	2·472	0·516	18·558
1865	4·006	1·839	1·423	0·468	3·048	0·684	2·931	5·171	0·169	7·355	2·662	1·461	31·220
1866	3·971	3·238	1·655	1·950	1·214	4·510	3·011	3·411	4·104	1·818	2·162	2·703	33·807
1867	2·564	1·938	2·171	2·822	3·350	1·062	4·103	2·155	2·060	1·856	0·320	2·041	26·442
1868	3·933	1·494	1·922	2·187	0·732	0·369	0·369	3·771	2·799	2·038	0·422	4·553	24·589
1869	3·435	2·410	1·476	2·129	3·226	1·065	0·971	1·351	2·788	2·019	2·383	3·198	26·481
1870	1·809	2·100	1·796	0·456	1·347	0·975	1·118	1·587	2·305	4·134	1·398	2·649	21·674
1871	1·454	1·630	1·503	2·882	0·964	3·864	3·996	0·770	4·073	1·786	0·659	1·419	25·000
1872	4·679	1·472	2·150	1·626	2·891	3·091	2·892	2·285	1·362	4·673	3·871	4·036	35·028
1873	4·019	1·342	2·046	0·631	1·657	1·746	2·534	2·689	2·376	2·826	1·990	0·713	24·569
1874	1·932	1·727	0·652	2·141	1·187	1·593	2·810	1·748	3·618	3·225	2·345	1·800	24·778
1875	3·993	1·176	0·868	1·558	2·736	3·528	5·660	1·102	2·800	5·898	4·432	1·189	34·940
1876	1·808	3·054	2·899	[3·333]	0·782	1·350	1·463	2·975	5·019	1·519	4·201	6·003	34·409
1877	4·990	2·098	2·550	2·762	2·824	1·435	3·284	2·596	1·529	1·950	5·159	2·279	33·456
1878	1·750	1·804	0·977	4·093	4·976	2·505	0·656	4·976	1·462	2·987	4·515	1·601	32·332
1879	2·849	3·799	1·183	2·790	3·481	5·551	4·244	[6·558]	3·131	0·815	0·814	0·823	36·038
1880	0·550	2·901	1·128	2·161	0·712	1·966	5·261	1·069	5·858	5·939	2·919	3·472	33·966

ırds are compared with the results shown by the large gauge Rothamsted * :—

LE III.—The AVERAGE MONTHLY and ANNUAL RAINFALL observed at EIGHT STATIONS during 27 YEARS, 1853–79.

	Within High Rainfall district.			Without High Rainfall district.				
	Rothamsted, Herts.	St. Albans, Herts.	Hemel Hempstead, Herts.	Hitchin, Herts.	Royston, Herts.	Cardington, Beds.	Stretham, Ely, Camb.	Greenwich, Kent.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
ary ..	2·67	2·69	2·61	2 15	2·07	1·83	1·42	2·18
uary ..	1·69	1·67	1·66	1·50	1·49	1·30	1·03	1·37
:h ..	1·71	1·81	1·74	1·50	1·52	1·33	1·20	1·47
l ..	2·00	1·91	1·86	1·70	1·59	1·51	1·38	1·68
.. ..	2·39	2·36	2·26	2·08	2·04	1·85	1·79	2·16
.. ..	2·47	2·37	2·35	2·06	1·91	2·06	1·97	2·16
.. ..	2·61	2·52	2·44	2·52	2·14	2·19	2·49	2·38
ıst ..	2·70	2·63	2·53	2·49	2·41	2·37	2·41	2·43
ember .	2·52	2·54	2·53	2·23	2·19	2·09	2·05	2·27
ber ..	2·98	2·84	2·76	2 51	2·31	2·17	2·00	2·67
ember ..	2·32	2·32	2·24	2·13	2·07	1·82	1·87	2·03
mber ..	2·03	2·13	2·08	1·79	1·78	1·53	1·33	1·87
	28·09	27·79	27·06	24·66	23·52	22·05	20·94	24·67

'he smallest fall of rain occurs in all cases in February and :ch; from this point there is at Rothamsted a steady ease up to July and August; there is then a slight decrease September, and the maximum rainfall of the year is reached October: after this there is a rapid fall to December, folled by a considerable rise in January. The records at Albans and Hemel Hempstead agree excellently with those Rothamsted, the latter station having, however, a somewhat ıter summer rainfall.

Vith Hitchin, Royston, Cardington, and Stretham, which in a different rainfall district, the maximum rainfall occurs August or July, not in October. At Greenwich, however,

* The records of the large gauge at Rothamsted do not compare exactly with e of the smaller gauges of other stations; while, however, the records of the e gauge are comparatively rather high, those of our 5-inch funnel gauge are ıe other direction. The excess of the large gauge over ordinary gauges is ›ably about 1 inch per annum. The rain-gauges employed at the various ions named are as under:—

		Height above ground.	Height above sea.
hamsted, size of gauges ..	87 × 72 in.	1 and 2 ft.	420 ft.
Albans, diameter of gauge	6 in.	2 ft. 0 in.	— „
nel Hempstead „	12 „	3 „ 9 „	237 „
chin „	8 „	1 „ 6 „	238 „
'ston „	8 „	0 „ 6 „	269 „
dington „	12 „	3 „ 0 „	109 „
etham, Ely „	9 „	4 „ 9 „	— „
enwich „	8 „	0 „ 5 „	155 „

the order of the rainfall agrees with that observed at Rothamsted, St. Albans, and Hemel Hempstead. The rainfall in both districts is very similar in the month of August; they differ most in January.

According to the rule adopted by many engineers, the driest year in a long series will have a rainfall one-third less, and the three consecutive driest years an average rainfall one-sixth less than the mean; while the rainfall in the wettest year will be one-third greater than the mean. The maximum rainfall is thus reckoned as twice as great as the minimum. The extreme rainfalls recorded at the eight stations just mentioned occurred as follows:—

	Wettest Year.	Driest Year.	Driest Three Years.
Rothamsted	1879	1864	1862–64
St. Albans	1872	1864	1854–56
Hemel Hempstead ..	1872	1864	1862–64
Hitchin	1860	1854, 1864	1862–64
Royston	1879	1864	1862–64
Cardington	1875	1870	1869–71
Stretham, Ely	1877	1854	1854–56
Greenwich	1860	1864	1856–58

The rainfalls recorded at these extreme periods of excessive rain or drought compare as follows with the quantities which would be calculated on the above mode of reckoning:—

Table IV.—The Rainfalls recorded in the Wettest, Driest, and Driest Three Consecutive Years during 27 Years, 1853-79, compared with the calculated Estimate.

	Wettest Year.		Driest Year.		Driest Three Consecutive Years.	
	Record.	Estimate.	Record.	Estimate.	Record.	Estimate.
Rothamsted	36·04	37·46	18·56	18·73	23·94	23·41
St. Albans	38·15	37·05	18·66	18·53	23·68	23·16
Hemel Hempstead ..	36·28	36·08	16·96	18·04	22·25	22·55
Hitchin	30·28	32·88	17·16	16·44	19·68	20·55
Royston	30·06	31·36	16·67	15·68	19·49	19·60
Cardington	31·39	29·40	14·87	14·70	18·30	18·37
Stretham, Ely	29·03	27·92	13·81	13·96	15·87	17·45
Greenwich	31·90	32·89	16·38	16·45	20·71	20·56
Mean	32·89	33·13	16·63	16·57	20·49	20·71

The agreement between the amounts of rain actually recorded and those calculated by the practical rules above referred to is

oughout very fair, and amply justifies their application to poses of water-supply.

3. *The Composition of the Rain-water.*

When the vapour of water is condensed in the upper regions the atmosphere, and descends in the form of rain, hail, snow, it reaches the earth holding in solution more or less he gases present in the atmosphere. The quantity of any dissolved by rain will depend on the solubility of that gas water, will be greater in proportion to the abundance of that in the atmosphere, and will also be greater, other circumices being equal, as the temperature of the rain is lower, the pressure of the atmosphere higher. In rain-water ected in the country nitrogen and oxygen will be the gases fly present, with a small quantity of carbonic acid, and ill smaller amount of carbonate of ammonium.

esides the gases which rain holds in solution, it contains ous solid substances gathered from the atmosphere during its ent. Some of these, as the chlorides, sulphates, and nitrates odium, calcium, and ammonium, are dissolved by the rain; rs, as particles of dust and soot, are merely mechanically l, and give to rain-water its ordinary dirty appearance. t of the constituents of rain-water are present in very minute ntity, and the powers of chemical analysis are taxed to the ost to determine them.

will be well to notice as briefly as possible the sources he more important matters dissolved by rain-water in its age through the air.

he ammonia of the atmosphere is derived from the decay of nal and vegetable matter, both on land and in the ocean, from the combustion of fuel, especially coal; the air of ns is much richer in ammonia than that of the country. ording to M. Schloesing, the ocean of the tropical regions is most important source of atmospheric ammonia. At the n temperature of tropical latitudes, the ammonia produced by decay of organic matter diffuses freely into the atmosphere, is carried by winds to all parts of the globe. In northern tudes southerly winds are those richest in ammonia.

he nitric acid present in the atmosphere is due in part to trical agency. Discharges of electricity in the air deterne the combination of the nitrogen and oxygen of which the nosphere is composed, nitrous acid being formed; ozone is at same time produced, which is capable of oxidizing both rous acid and ammonia, nitric acid in each case resulting. source of nitric acid independent of electrical discharge,

exists in the oxidation of ammonia by ozone and peroxide of hydrogen. As the latter substance is evolved when turpentine, and possibly other bodies, are oxidised in the air, the neighbourhood of a pine-forest should be favourable to the formation of nitric acid in the atmosphere.

The sulphates of the atmosphere are, according to Angus Smith, chiefly derived from the oxidation of the sulphur compounds evolved during the decay of animal matter. In towns the sulphates are much increased by the oxidation of the sulphurous acid contained in coal-smoke.

Chlorides are principally furnished by the sea, fine spray of salt-water being carried long distances by high winds. To a small extent chlorides may also be furnished by the combustion of fuel.

The quantity of ammonia and nitric acid contained in rain-water is a question of considerable interest to the agriculturist. As ammonia and nitric acid form the chief if not the only sources of the nitrogen of plants, and manures containing them are purchased by the farmer only at considerable expense, it becomes of great interest to ascertain the amount naturally supplied to our fields by rain.

De Saússure, Brandes, and Liebig had called attention to the existence of ammonia and nitric acid in rain-water before the commencement of the Rothamsted experiments. Some initiative determinations of the ammonia in rain were made at Rothamsted as early as 1846. Barral, in 1851, made determinations of both the nitric acid and the ammonia in the rain which fell in Paris during several consecutive months; and in 1852 Boussingault determined the ammonia in the rain collected at Liebfrauenberg, in Alsace. The opportunity afforded by the erection of the large gauge at Rothamsted of collecting considerable quantities of rain-water at a distance from any large town* was at once turned to account to follow up the subject. A fixed proportion of the day's rainfall was regularly set aside, and these quantities being mixed at the end of the month, a sample was obtained accurately representing the month's rainfall. Determinations of ammonia were made in these monthly samples for 15 months during 1853 and 1854. The method employed consisted in fractional distillation of the water, and determination of the ammonia in the distillate with a very dilute standard acid and alkali. The results of these analyses were communicated to the British Association for the Advancement of Science in 1854, and to the Report of the Association

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* Rothamsted lies about 25 miles north-west of London, and about four miles north of St. Albans. The village of Harpenden, with a very scattered population of nearly 3000, lies mostly to the north-east and east of the [illegible] *majority* of the houses being probably about three-quarters of a mile [illegible]

hat year we must refer for all details of this investigation.*
'able V. will be found a summary of the results.
he amount of nitrogen existing as ammonia is given in s per million. This mode of reckoning will be adopted ughout the present paper; partly because any smaller unit ılves the use of long decimals, and partly because results expressed are equally intelligible to foreign and English ers; 'parts per million' are, indeed, identical with the ligrams per litre,' commonly employed on the Continent. those English readers to whom a million may appear a ıe term we may here state that 1 inch of water per acre ;hs 226,263 lbs., consequently 10 parts per million of ›gen, or of any other constituent of rain or drainage-water, :spond to 2·26 lbs. per acre for each inch of rain or drainage.

.ᴇ V.—Nitrogen existing as Ammonia in Rain-Water collected at Rothamsted 1853–4.

	1853.			1854.		
	Rainfall.	Nitrogen as Ammonia.		Rainfall.	Nitrogen as Ammonia.	
	Inches.	Per Million of Rain.	Per Acre. lbs.	Inches.	Per Million of Rain.	Per Acre. lbs.
ıry	..	..	..	2·034	0·64	0·30
ary.. ..	..	..	..	0·949	0·78	0·17
ı	2·363	1·19	0·63	0·514	0·78	0·09
.. ..	2·999	0·67	0·46	0·498	0·80	0·09
. .. ..	1·682	1·10	0·42	4·384	0·37	0·38
.. ..	3·395	1·05	0·80	..	..	..
. .. ..	4·484	0·77	0·78	..	..	..
ıt	2·978	0·69	0·46	..	..	..
mber ..	2·011	0·61	0·28	..	..	..
er	3·659	0·57	0·47	..	..	..
nber ..	2·052	0·66	0·31	..	..	..
ıber ..	0·408	1·33	0·12	..	..	..

e have here during the first 12 months a total rainfall of 14 inches, containing nitrogen in the form of ammonia 1 to 5·20 lbs. per acre. In the whole 15 months over which determinations range we have a rainfall of 34·41 inches, ıining on an average 0·74 of nitrogen, as ammonia, per ıon of water.†

On the Amounts of, and Methods of estimating Ammonia and Nitric Acid in Water." By J. B. Lawes and Dr. J. H. Gilbert. Report of British Asso- n, 1854.

'his average is not the mean of the fifteen monthly proportions of nitrogen illion given in the table, which would amount to 0·80, but is arrived at by ng the total lbs. of nitrogen per acre contained in the fifteen months' rain total lbs. of rain per acre which fell in that period; the figure thus arrived ly represents the composition of the water, supposing the whole rainfall of een months had been mixed together. The same method will be employed ulating *general averages* throughout this paper.

An attempt was made to determine the small amount of nitrogen existing as nitric acid in some of the above rain-waters, but the methods then known did not prove sufficiently accurate for the purpose.

The rain collected at Rothamsted during 1855 and 1856 was analysed by Professor J. T. Way; he determined the quantity both of ammonia and nitric acid in mixed samples of water representing the rainfall of each month. The ammonia in the rain was determined by a method similar in principle to that employed at Rothamsted. The nitric acid was determined by a new and delicate method devised for the purpose by Professor Way. The details of this investigation will be found in the 'Royal Agricultural Society's Journal,' vol. xvii. 142, 618. A summary of the results is given in Table VI. The figures given by Way have been recalculated so as to compare with the other analyses in this Paper.

TABLE VI.—NITROGEN as AMMONIA and NITRIC ACID in RAIN-WATER collected at ROTHAMSTED in 1855 and 1856.

	1855.			1856.		
	Rainfall Inches.	Nitrogen per Million.		Rainfall Inches.	Nitrogen per Million.	
		As Ammonia.	As Nitric Acid.		As Ammonia.	As Nitric Acid.
January	0·598	1·08	0·06	2·782	0·93	0 09
February	0·993	1·22	0·16	1·352	1·60	0·07
March	2·364	1·01	0·08	1 004	1·09	0·13
April	0·410	1·45	0·13	2·611	1·72	0·07
May	2·324	0·94	0·13	4·707	1·49	0·10
June	1·647	1·59	0·30	1·912	1·33	0·17
July	6·956	0·72	0·06	1·484	1·00	0·13
August	2·633	0·94	0·22	2·645	0·82	0·13
September	1·545	1·12	0·08	2·187	1·42	0·13
October	5·501	0·72	0·13	2·874	0·71	0·13
November	2·473	0·64	0·07	1·422	0·94	0·16
December	1·722	0·79	0·06	2 235	0·94	0·15
Whole Year ..	29·166	0·88	0·12	27·215	1·18	0·12

It appears that on the whole a somewhat larger amount of ammonia was found by Way than in the previous determinations at Rothamsted; this is especially the case in the analyses of rain-water collected in 1856. On the average of the whole 24 months Way found the proportion of nitrogen in the form of ammonia to be 1·03 per million of rain-water. The nitrogen existing as nitric acid in a far smaller quantity, [illegible]

24 months only 0·12 per million. Boussingault had found ain-water collected on a wooded hillside at Liebfrauen-, from May to November 1852, an average of 0·48 parts itrogen as ammonia per million of water. In rain collected he same place at a similar time of year in 1856 and 1857, ound the nitrogen as nitric acid to average only 0·048 per ion.

he results given in Tables V. and VI. show that the ntity of ammonia in rain-water is subject to very con-rable variation. This difference is partly due to a variation he quantity of ammonia present in the atmosphere. Under ral conditions the air will be richest in ammonia in summer-, and generally when a warm wind is blowing. In towns, ever, where much ammonia is produced by the combustion oal, the winter may be the period when ammonia is most ndant in the atmosphere. At Rothamsted the rain is appa-ly richest in ammonia in summer-time. If we take the rminations made during the first 12 months at Rothamsted, the subsequent two years' analyses by Way, and separately nge those relating to what for our purpose we may call mer and winter periods, we arrive at the following average lts:

ABLE VII.—NITROGEN as AMMONIA in the RAIN of SUMMER and WINTER PERIODS; AVERAGE of THREE YEARS.

	RAINFALL. Inches.	Nitrogen as Ammonia. Per Million of Rain.	Nitrogen as Ammonia. Pounds per Acre.
ıer (April to September)	16·203	1·02	3·74
r (October to March)	12·262	0·85	2·36
Whole Year	28·465	0·95	6·10

ıe nitric acid shown by Way's analyses is also slightly er in the summer period, the average of two years giving he summer rain 0·122, and for the winter rain 0·109 of gen per million.

ıother condition which has a still greater influence on the ortion of ammonia in rain is the amount and distribution ıe rainfall. A heavy rainfall descending in a short time always be poorer in ammonia than the rain of light showers ibuted over a considerable period, the former rain-water

having come in contact with a relatively smaller volume of air than the latter. Moreover, in a storm, or a consecutive rainfall, the latter part of the rain passes through an atmosphere already well washed, while in light showers the atmosphere is more or less renewed between each rainfall. The influence of the quantity of the rain on the proportion of ammonia it contains will be plainly seen if we arrange the 39 monthly analyses of rain-water already given according to the amount of rainfall in each month, as is done in the following Table:

TABLE VIII.—NITROGEN as AMMONIA in MONTHLY RAINFALLS arranged according to the AMOUNT of FALL.

	Average Rainfall.	Nitrogen as Ammonia, per Million.
	inches.	
Rainfall below 1 inch (7 months)	0·624	1·06
Rainfall between 1 and 2 inches (9 months)	1·530	1·17
Rainfall between 2 and 3 inches (16 months).. ..	2·473	0·91
Rainfall above 3 inches (7 months)	4·727	0·82

The smallest rainfall does not here contain the largest proportion of ammonia, the maximum of ammonia occurring in the rainfall standing second in the Table, but on the whole the proportion of the ammonia plainly falls as the amount of rain increases.

The nitrogen existing as nitric acid follows a similar order. The rain of three months in which the fall was below one inch, contained as an average 0·12 of nitrogen as nitric acid per million. The average of eight months, with a fall between one and two inches, was 0·14 of nitrogen per million. Ten months, with a fall between two and three inches, gave an average of 0·12 of nitrogen per million; while three months, with a fall exceeding three inches, gave 0·10 of nitrogen per million.

It appears that the smallest rainfall was not quite the richest either in ammonia or nitric acid. It may of course happen that a small monthly rainfall may not be a distributed one, but fall in a few heavy showers. A more general explanation appears to be that the conditions most favourable to a high proportion of ammonia in the rain-water (as a sudden change from a warm to a cold wind) are conditions generally attended by a somewhat considerable rainfall.

The determinations of ammonia made in three years' rainfall, and the determinations of nitric acid in two years' rainfall, lead to the following conclusions as to the quantity of nitrogen in these forms annually supplied to the soil by rain.

TABLE IX.—NITROGEN as AMMONIA and NITRIC ACID in the RAINFALL of THREE YEARS, in lbs. PER ACRE.

Years.	Rainfall.	Nitrogen per Acre, as		
		Ammonia.	Nitric Acid.	Total Nitrogen.
	inches.	lbs.	lbs.	lbs.
1853–4	29·014	5·20	[0·74]	5·94
1855	29·166	5·82	0·72	6·58*
1856	27·215	7·28	0·76	8·00*
Mean ..	28·465	6·10	0·74	6·84

Thus on an average of three years, with a mean rainfall of 28·465 inches, we have 6·10 lbs. of nitrogen as ammonia supplied to the soil per acre each year; and in addition, on an average of two years, 0·74 lb. of nitrogen in the form of nitric acid; giving a total of 6·84 lbs. of nitrogen. If, however, we only regard the two years in which the nitric acid was actually determined, the total nitrogen becomes 7·29 lbs. per acre, equivalent to 46¼ lbs. of ordinary nitrate of sodium. It must be recollected in dealing with these figures, that the analyses on which they are based were made at a time when many of the modern refinements in chemical methods were unknown. Further on we shall compare these results with those obtained more recently, both by others and at Rothamsted.

The amount of ammonia supplied to the soil by rain does not of course represent the whole amount furnished by the atmosphere; we have also to take into account the direct absorption by the soil itself. The quantity of ammonia annually absorbed from the atmosphere by a moist soil is doubtless considerable, but in the present state of our knowledge no estimate of the amount can be made; we shall, however, refer to the point again further on.

The next analyses of Rothamsted rain-water we have to notice are those made by Dr. E. Frankland, and published in the Sixth Report of the Rivers' Pollution Commission, 1874, p. 27. This series includes 71 samples of rain- and snow-water collected in the first large gauge between April 1869 and May 1870, and 7 samples of dew and hoar-frost collected within the same period. The examination to which these waters were submitted was far more complete than in any of the preceding analyses, the work in fact stands in some respects unique among investigations of the kind hitherto published. Dr. Frankland determined the total solid matter dissolved in the water, and the quantity of carbon and nitrogen existing in the form of organic matter, besides making determinations of the ammonia, nitric acid, and

* These figures stand respectively as 6·63 lbs. and 8·31 lbs. in Way's original paper; the figures *in this Table* are more correct.

chlorine present; the hardness of the water was also determine The methods of analysis employed by Dr. Frankland are de scribed in the Appendix to the Report just mentioned, and al in the 'Journal of the Chemical Society,' 1868, p. 77.

The waters examined by Dr. Frankland were either fa samples of individual rainfalls, or represented the water collect during some part of a fall. The samples by no means represe all the rainfalls of a year, or even of any month, and the analys are therefore insufficient for calculating the total amount nitrogen or chlorine furnished by the rain in the course of year; but they illustrate excellently the variations in the co position of rain-water under various conditions, which inde was a special object of the inquiry.

It is obvious that the water falling on a rain gauge must apt to carry with it into the receiver any impurity found on t surface of the gauge. Dust of various kinds is continual blown on to the surface of the gauge, which is also sometim though rarely, contaminated by the excrements of birds; sm insects also frequently find their way into the collecting vesse With the view of removing as far as possible these sources error, certain samples of rain were collected for analysis after t surface of the gauge had been washed by distilled water; oth samples were collected during the latter part of a shower, af the collecting surface had been washed by the earlier rain. T samples thus collected were for the most part received at on into clean bottles, without first entering the ordinary receiv of the gauge. Twenty-two samples of rain-water were in collected with one or other of these precautions. The me composition of these waters, and of the waters in the collecti of which no such precautions were taken, is shown in t following Table:

TABLE X.—AVERAGE COMPOSITION of RAIN-WATER collected both fr WASHED GAUGE, and WITHOUT special PRECAUTION, in parts per Mil

	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as				Chlorine.	Har
			Organic Matter.	Ammonia.	Nitrates and Nitrites.	Total Nitrogen.		
From washed gauge, 22 samples	28·0	0·64	0·16	0·30	0·12†	0·58	2·1	·
Without special precaution, 47 samples	36·6	1·03	0·20	0·41	0·15‡	0·76	3·6	·

* By "hardness" is understood the total lime and magnesia in a wat expressed in parts of carbonate of calcium.

† Mean of 11 analyses. ‡ Mean of 23 analyses.

would appear from these figures that the water collected the washed gauge was distinctly purer, especially in ic carbon and chlorine, than the rain ordinarily collected. e figures, however, probably exaggerate the effect produced le natural impurities of the collecting surface, for the rity of the 22 samples being collected during the middle tter part of a shower, really indicate the results obtained a partly washed atmosphere as well as from a washed :. The extent to which the composition of the rain is ident on the washed or unwashed condition of the atmoe is well illustrated by two of Dr. Frankland's analyses. he 11th of May, 1870, rain being anticipated, the rain : was washed with distilled water at 11.30 A.M.; a collecof rain was then made at 3 P.M., and a second at 4.30 P.M. : two samples of water were found to contain per million lows:

	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as				Chlorine.
			Organic Matter.	Ammonia.	Nitrates and Nitrites.	Total Nitrogen.	
on at 3 P.M....	40·8	0·93	0·18	1·07	0·18	1·43	1·0
4.30 P.M.	29·4	0·62	0·19	0·37	0·13	0·69	0·8

: second collection of rain-water is seen to be far purer the first, the earlier rain having removed from the atmo: much of the ammonia, chlorides, and organic dust which riously contained.

onsidering the results obtained by Dr. Frankland, it will ivenient to look in the first place at the general composif the rain-water, and afterwards at that of the dew and rost as shown by his analyses; and then at the variations composition under various circumstances.

o of the samples of water analysed by Dr. Frankland are led from the mean given in the following Table, and will luded from all subsequent discussion. They represent the ions from January 25 to 31, and from February 9 to 16, Hard frost occurred on both occasions, and hoar-frost w remained exposed for many days on the surface of the , and doubtless became contaminated to an unusual extent tmospheric dust, as the resulting samples of water proved npure.

Dr. Angus Smith has shown form a large ingredient of rain-water.

We turn now to the analyses of dew and hoar-frost. The samples examined were seven in number. In the case of some of the samples the collection extended over several days, and embraced many distinct deposits.

TABLE XII.—The MAXIMUM, MINIMUM, and MEAN AMOUNTS of certain CONSTITUENTS in SEVEN SAMPLES of DEW and HOAR-FROST, in parts per MILLION.

	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as Organic Matter.	Nitrogen as Ammonia.	Nitrogen as Nitrates and Nitrites.	Total Nitrogen.	Chlorine.	Hardness.
Highest proportion	80·0	4·50	1·96	2·31	0·50	4·55	8·0	25·0
Lowest proportion..	26·4	1·95	0·26	1·07	0·28	1·66	3·5	13·0
Mean, 7 samples ..	48·7	2·64	0·76	1·63	0·40*	2·79	5·3	19·0

These small deposits, condensed from the lower stratum of the atmosphere, contain on an average three or four times the amount of organic carbon, organic nitrogen, ammonia, and nitric acid, found in the analyses of rain-water. The total quantity of solid matter, and the amount of chlorides, is also larger, but the difference is much smaller than in the case of the other ingredients. The mean proportion of organic nitrogen to carbon is 1 : 3·5.

We must now consider briefly the variations in the composition of the Rothamsted rain-waters displayed in Dr. Frankland's analyses. The extent of variation in 69 samples has been already given in Table XI. A glance at this Table will at once show that the amount of variation is enormous; and the range of difference becomes still larger if we include in the same view the small deposits of dew and hoar-frost.

As the composition of rain-water greatly depends on the quantity of the fall, we shall in the first place classify the analyses according to the quantity of rain which they represent, and next according to the season of the year in which they fell. Only fifty-four of the samples analysed by Dr. Frankland fairly represented a known quantity of rainfall, but in the case of four other samples the bulk of the sample bore such a high proportion to the bulk of the rainfall that it may be accepted as a

* Mean of 4 analyses.

rably fair representation of the whole fall. From the whole iber two analyses are omitted for reasons already given; e remain therefore fifty-six available for discussion.

ı the upper division of Table XIII. the whole of the analyses 'ain-water are arranged according to the quantity of the fall ch they represent. It is evident on considering this division ; the proportion of each constituent tends to diminish as the ›unt of rainfall increases, the decrease being most rapid in case of the chlorides, and least marked in the case of the anic elements. The quantity of nitrogen as nitrates and ites is frequently the mean of so few analyses that the figures necessarily irregular.

ɪʟᴇ XIII.—The Composition of Rain-Water in relation to the Amount of Rainfall and Season of the Year.

Quantity of Rainfall.	Number of Samples.	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as Organic Matter.	Nitrogen as Ammonia.	Nitrogen as Nitrates and Nitrites.*	Nitrogen as Total Nitrogen.	Chlorine.
In the Whole Year.								
›w ·10 inch	22	38·2	0·95	0·21	0·46	0·12	0·79	4·2
m ·10 to ·20 inch ..	20	36·9	1·19	0·23	0·44	0·17	0·84	3·5
m ·20 to ·40 inch ..	7	34·9	0·74	0·14	0·23	0·11	0·48	1·8
n ·50 to ·90 inch ..	7	21·5	0·71	0·12	0·26	0·18	0·56	1·5
In the Summer Months, April to September.								
w ·10 inch	10	42·2	1·10	0·17	0·48	0·17	0·82	3·2
ı ·10 to ·20 inch ..	14	41·9	1·18	0·18	0·43	0·18	0·79	3·6
ı ·20 to ·40 inch ..	4	42·6	1·01	0·15	0·25	0·12	0·52	2·3
ı ·50 to ·90 inch ..	4	26·3	0·97	0·11	0·35	0·38	0·84	1·9
In the Winter Months, October to March.								
w ·10 inch	12	35·0	0·83	0·25	0·44	0·10	0·79	5·0
n ·10 to ·20 inch ..	6	25·1	1·22	0·33	0·48	0·16	0·97	3·3
n ·20 to ·40 inch ..	3	24·6	0·39	0·13	0·20	0·09	0·42	1·2
m ·50 to ·90 inch ..	3	15·1	0·37	0·14	0·14	0·08	0·36	0·9

The figures for the nitrogen present as nitrates and nitrites are the means of rminations made in the following samples:—

elow ·10 inch	Summer, 2;	Winter, 8;	Whole Year,	10 samples.
rom ·10 to ·20 inch ..	„ 7	„ 6	„ „	13 „
rom ·20 to ·40 inch ..	„ 1	„ 1	„ „	2 „
rom ·50 to ·90 inch ..	„ 1	„ 2	„ „	3 „

Since the quantity of the fall exercises such a preponderating influence on the composition of the rain-water, it is clear that in tracing out other conditions affecting the composition of the water we should only compare together analyses which represent *rainfalls of similar amount*, a truth which, though self-evident, has been very much overlooked in discussions of this nature.

In the second and third divisions of the Table the analyses are still arranged according to the quantity of the fall, but they are now divided so as to show the differences between the rain of summer and winter. The series of analyses we are now discussing is by no means favourable for the exhibition of differences of composition due to season, very few of the samples having been collected either in the height of summer or the depth of winter. Thus out of the fifty-six samples there is not one collected in August, and but one in July; there is but one in December, and there are only two each in November and January. The most abundant collections were in May, April and September, among the summer months, and in February, March, and October, among the winter months.

Notwithstanding, however, the small number, and partial distribution of the samples available for discussion, the result of their classification into summer and winter periods is generally consistent and full of interest. In every case the amount of total solid matter dissolved in the rain-water is considerably greater in summer than in winter. In a majority of cases the ammonia is greater in summer than in winter. The nitric acid is also in every case greatest in summer-time, though the figures are very irregular, owing to the small number of analyses at command. The general distribution of ammonia and nitric acid is thus the same as that shown in the earlier analyses of Rothamsted rain-water.

The most striking difference in the two seasons occurs in the organic matter. The total organic matter is in a majority of cases greater in summer than in winter; its composition, however, is quite distinct. In summer the carbon is generally greater than in winter, while the nitrogen in summer is less than in winter. The proportion of nitrogen to carbon is thus very different at the two seasons of the year, as will appear more clearly from the Table on the opposite page.

The simplest explanation of these facts seems to be that in summer-time the organic matter in rain-water contains a larger proportion of fresh vegetable matter than in winter; in the latter season the organic impurity must consist chiefly of products of decay.

TABLE XIV.—AVERAGE PROPORTION of ORGANIC NITROGEN to CARBON in RAINFALLS of different AMOUNT, and collected at different SEASONS of the YEAR.

Quantity of Rainfall.	Summer.	Winter.	Whole Year.
Below ·10 inch	1 : 6·4	1 : 3·4	1 : 4·5
Between ·10 and ·20 inch	1 : 6·5	1 : 3·7	1 : 5·3
Between ·20 and ·40 inch	1 : 6·8	1 : 2·9	1 : 5·3
Between ·50 and ·90 inch	1 : 8·8	1 : 2·7	1 : 5·8

The arrangement of the few analyses of dew and hoar-frost in summer and winter groups shows, as in the case of rain, a preponderance of total solid matter, of organic matter, and of ammonia, in the summer months; but the series is too small for detailed discussion.

Dr. Frankland has paid considerable attention in his Report to the influence of various winds on the composition of the rain-water collected at Rothamsted. The question obviously presents considerable difficulty. To compare under equal conditions the rain produced by different winds, we must clearly only compare rains of similar quantity, and falling in a similar season of the year. This can hardly be done to any practical extent with the small series of analyses now before us. The chief points insisted on by Dr. Frankland, namely, that the south-east wind produces rain richest in ammonia, and the north-east wind rain richest in chlorine, are probably correct. London lies to the south-east of the rain-gauge; the south-east wind, which is naturally rich in ammonia, may probably derive some addition to its contents from this source. To the north-east of the gauge lies the nearest wide expanse of ocean—the North Sea; it is easy therefore to understand that winds from this direction should supply the largest proportion of chlorides.

The last investigation on the Rothamsted rain-waters which we have to mention is one now in progress respecting the quantity of chlorides present in the annual rainfall. This investigation commenced in June 1877, and has been continued down to the present time. A proportion of each day's rain, at the rate of one gallon for every inch of rainfall, has been set aside in a glass carboy provided for the purpose. At the end of each month the contents of the carboy are well mixed, and a sample is taken for analysis.

The chlorine has been determined by the volumetric method employed by Dr. Frankland. The amount of chlorine present

being often extremely small, and the results obtained when working on the unconcentrated water depending greatly on the conditions of the experiment, the greater part of the determinations has been made on water concentrated in a glass basin. One litre of rain-water, with 10 cubic centimetres of lime-water (since May 1880, 5 cubic centimetres have been employed), have been evaporated over a gas burner to rather less than one-quarter litre, then filtered, and the clear liquid diluted with distilled water till exactly one-quarter of a litre in volume; in this solution chlorine has then been determined by the method already mentioned. This mode of working gave much sharper results. We have, however, quite recently found that the chlorine determined on this plan is somewhat below the true amount. We have, therefore, latterly concentrated two or three litres of the rain with a little lime-water to a small bulk, filtered, precipitated with nitrate of silver, and collected and weighed the precipitate. Eight monthly determinations of chlorine in rain-water made by this gravimetric method have given a mean of 2·89 parts of chlorine per million, while the results of the volumetric method for the same months show a mean of 2·73 of chlorine per million.

In the following Table (XV.) will be found the monthly determinations of chlorine made by the volumetric method. The results, though a little below the truth, are at least comparable amongst themselves, and exhibit some interesting features.

The range in the amount of chlorides shown by these analyses is very considerable. Thus the rain of July 1880 contained, by the method of analysis here employed, only 0·10 part of chlorine per million of water, while the rain and snow of November 1879 contained 9·38 parts of chlorine. The latter figure is, however, quite exceptional, and suggests a possible contamination of the water. The second highest amount reached in the forty-three months is much lower, namely, 5·80 parts of chlorine. The average proportion of chlorine in the rain-water during the whole period is 1·75 per million. The quantity of chlorine brought by the rain on to an acre of land in the course of a year (average of 3½ years) is 13·42 lbs., for a rainfall of 34·038 inches, equal to 22·12 lbs. of pure common salt. All these figures, as already mentioned, are somewhat below the truth.

With the view of throwing light on the cause of variation in the proportion of chlorides, we proceed as before to classify the analyses according to the amount of rainfall, and according to the season of the year.

Table XV.—Monthly Determina[illegible], during [illegible] Months, 1877–80.

	1877.			1878.			1879.			1880.		
	Rainfall.	Chlorine per Million of Rain.	Chlorine per Acre.	Rainfall.	Chlorine per Million of Rain.	Chlorine per Acre.	Rainfall.	Chlorine per Million of Rain.	Chlorine per Acre.	Rainfall.	Chlorine per Million of Rain.	Chlorine per Acre.
	Inches.		lbs.	Inches.		lbs.	Inches.		lbs.	Inches.		lbs.
January	..	..	..	1·750	2·91	1·15	2·849	3·04	1·96	0·550	3·20	0·40
February	..	..	..	1·804	0·50	0·20	3·799	1·83	1·57	2·901	3·20	2·10
March	..	..	..	0·977	4 00	0·88	1·183	5·80	1·55	1·128	2.90	0·74
April	..	..	..	4·093	0·55	0·51	2·790	1·67	1·05	2·161	1·73	0·85
May	..	..	..	4·976	0·91	1·03	3·481	1·40	1·10	0·742	3·43	0·58
June	1·435	1·95	0·63	2·505	1·48	0·84	5·551	0·80	1·01	1·966	1·80	0·80
July	3·284	0·24	0·18	0·656	4·31	0·64	4·244	0 80	0·77	5·261	0·10	0·12
August	2·596	0·95	0·56	4·976	1·16	1·31	6·558*	0·85	1·26	1·069	1·30	0·31
September	1·529	1·73	0·60	1·462	2·28	0·75	3·131	1·05	0·74	5·858	0·97	1·29
October	1·950	3·40	1·50	2·987	2·58	1·74	0·815	2·65	0·49	5·939	3·00	4·03
November	5·159	1·97	2·29	4·545	1·83	1·88	0·814	9·38	1·73	2·919	2·95	1·95
December	2·279	1·96	1·01	1·601	3·00	1·09	0·823	5·75	1·07	3·472	1·70	1·34
Totals and Averages	18·232	1·64	6·77	32·332	1·64	12·02	36·038	1·75	14·30	33·966	1·89	14·51

* The sample actually taken for analysis represented only 3·55 inches; the water collected by the large Rain-gauge on August 2–3, having been contaminated by the flood which surrounded the gauge, was rejected.

parts of the continent of Europe. The results of twenty-two determinations, each extending over a whole year, and made at nine different stations, will be found in Table XVIII.

TABLE XVIII.—DETERMINATIONS of the QUANTITY of NITROGEN supplied by RAIN, as AMMONIA and NITRIC ACID, to an ACRE of LAND, during ONE YEAR.

STATION.	Rainfall.	Nitrogen per Million, as		Total Nitrogen per Acre.
		Ammonia.	Nitric Acid.	
	Inches.			lbs.
Kuschen, 1864-5	11·85	0·54	0·16	1·86
" 1865-6	17·70	0·44	0·16	2 50
Insterburg, 1864-5	27·55	0·55	0·30	5·49
" 1865-6	23·79	0·76	0·49	6·82
Dahme, 1865	17·09	1·42	0·30	6 66
Regenwalde, 1864-5	23·48	2·03	0·80	15·09
" 1865-6	19·31	1·88	0·48	10·38
" 1866-7	25·37	2·28	0·56	16·44
*Ida-Marienhütte; mean of 6 years, 1865-70	22·65	..	..	9·22
Proskau, 1864-5	17·81	3·21	1·73	20·91
Florence, 1870	36·55	1·17	0·44	13·36
" 1871	42·48	0·81	0·22	9·89
" 1872	50·82	0·82	0·26	12 51
Vallombrosa, 1872	79·83	0·42	0·15	10·38
Montsouris, Paris, 1877-8	23·62	1·91	0·24	11 54
" 1878-9	25·79	1 20	0·70	11·16
" 1879-80 ..	15·70	1·36	1·60	10·32
Mean of 22 years	27·03	..	..	10·23

The large amount of nitric acid found in many of these rain-waters is remarkable. It would appear also, from the results at Regenwalde and Montsouris, that the quantity of nitric acid may vary extremely from year to year in the same place. Are we to assume that the large quantities of nitric acid indicated have been produced by the union of atmospheric nitrogen and oxygen under electrical influences, or chiefly through the oxidation of the ammonia of the air by means of ozone or peroxide of hydrogen? The latter alternative seems the most probable.

It is seen that the numerous widely varying determinations, some made in the vicinity of towns, give a mean of 10·23 lbs. of combined nitrogen annually supplied per acre by rain, with a mean rainfall of 27·03 inches. The two years' determinations (1855–6) of both ammonia and nitric acid in the rain at Rotham-

* Details of these results are not at hand. The rainfall given is really the average of seven years, 1864-70.

ave, as has been seen, 6·58 lbs. and 8·00 lbs. of combined
en as the annual supply per acre from the same source.*
king all allowance for far inland open country positions
e one hand, and for proximity to towns on the other, the
small amounts of combined nitrogen so supplied per acre
ne of the cases recorded in the Table, and the compara-
large quantities in others, seem difficult to explain, or
oncile with one another. Nor do the results become
intelligible when considered in relation to those discussed
e foregoing pages, and to the comparatively limited and
rm amounts recorded for Montsouris, within the walls of
. As to the higher amounts, it is true that Liebig, in his
r writings, assumed the probability of a very much larger
ity of ammonia coming down in rain than any indicated
above Table, or than he did subsequently; and even in
ore recent work, 'The Natural Laws of Husbandry,' pub-
l in 1863, he supposes that as much as 24 lbs. of nitrogen
re may be annually available to vegetation from that source.
l be observed, however, that neither do the early results for
pen country obtained by Boussingault, nor do those ob-
l at Rothamsted, indicate more than about one-third of this
nt; and the more recent determinations in the Rothamsted
raters point to less rather than more than the earlier ones.

II. The Amount and Composition of the Drainage-Waters from Land unmanured and uncropped.

ny inquiry respecting the influence of drainage in practical
lture, it is clearly of primary importance to ascertain what
rtion of the rainfall passes in each season through known
s of soil; we shall therefore in the first place describe the
iments relating to this part of the subject.

e amount of drainage-water passing through any soil
ds—1. On the amount of the rainfall. 2. On the
cal condition of the soil, its permeability, and water-hold-
ower. 3. On the amount of evaporation taking place,
latter is determined by the temperature of the soil and air,
y the capillary power of the soil, and is greatly increased
a crop is growing on the surface.

e experiments we are about to describe were made to
tain the amount of natural drainage through the Rothamsted
when kept bare of vegetation; the effect of a crop is thus

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he recent determinations of ammonia in the Rothamsted rain (see Note, p. 19) point to a still smaller amount of total combined nitrogen supplied per n the average annual rainfall, probably not more than 4–5 lbs.

for the present excluded. The drainage-waters obtained have been analysed; their composition will be found to illustrate in a striking manner the loss of plant food which an uncropped soil may suffer from the percolation of rain-water.

1. *The Drain-Gauges.*

The drain-gauges which have been constructed are three in number; they consist of rectangular plots of soil, each 6 feet by 7 feet 3 inches, having thus the same surface as that of the large rain-gauge, namely 1-1000th of an acre. The depth of the soil varies. In the first gauge the depth is 20 inches; in the second it is 40 inches; and in the third 60 inches.

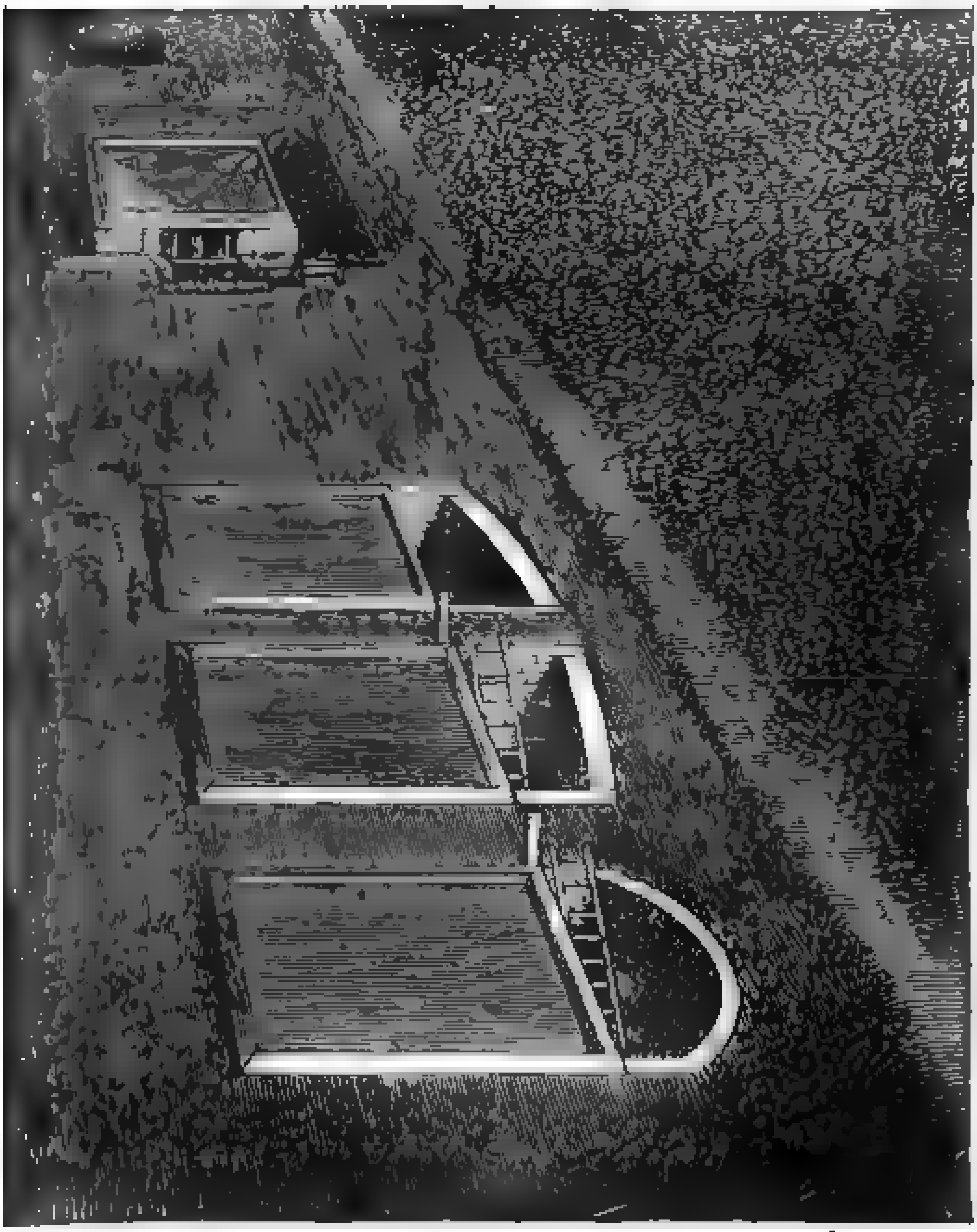
In order to obtain a natural drainage, it was of primary importance that the soil should be in a perfectly natural condition of consolidation, neither more porous nor more condensed than the ordinary field soil. To accomplish this object a deep trench was dug along the front of each intended gauge; the mass of soil was then gradually undermined at the depth previously determined, and plates of cast-iron, 8 inches wide and perforated with holes, were introduced to support the soil as the work proceeded. This perforated iron bottom was finally strengthened by transverse iron girders, and the ends of the plates and girders supported by brickwork on three sides of the intended gauge. The soil being now supported from beneath, trenches were made one by one on the three remaining sides of the block of soil to be isolated; walls of brick, laid in cement, 4½ inches thick, were built against the soil, and the trenches were again filled in with earth. The mass of soil was in this manner built in on all sides with brick and cement. The surrounding walls were carried 3 inches above the level of the soil, the edges at the top being made to slope outwards. A sketch of the three drain-gauges will be found in Fig. 2, which also shows the position of the large and small rain-gauges.

At about 1 foot 6 inches below the perforated iron bottom is fixed a large zinc funnel, of the same area as the soil above it; the drainage-water from the soil falls on to this funnel, and is received in suitable vessels placed beneath. During the first three years the water was collected in glass carboys, and its quantity determined by weight; but since December, 1873, galvanised-iron cylinders, fitted with external gauge tubes, have been employed for receiving and measuring the water; these cylinders are quite similar to those used for the large rain-gauge.

The drain-gauges just described were constructed in Barnfield; and the new large rain-gauge was afterwards constructed in their immediate neighbourhood. The soil at Rothamsted

sts generally of a somewhat heavy loam, with a subsoil of both mixed with flints, and lying on chalk, which, however, m comes very near the surface. In the present case the vated soil of the field was about 8 inches in depth; this was eded by about 10 inches of friable clay, followed by a subsoil ther stiff clay. The whole of the experimental soil was e the chalk. The land had previously been under the ary arable culture of the farm.

Fig. 2.—*View of the Rain- and Drain-gauges.*



gauges were constructed in the summer of 1870; since few alterations have been made. In November and ber 1874, leakage from the outside being feared, the sides gauges were bared, the old walls coated with cement, and ickened by an additional half-brick. Again, in February

1879, the drainage from the 20-inch gauge appearing very excessive, one of the walls was bared in which a leak was suspected, and its external surface coated with cement.

2. *The Measured Drainage, and the Evaporation.*

The amount of the monthly drainage through each of the three gauges, from September 1870 to the end of 1880, is shown in Table XIX.*

The monthly drainages recorded in Table XIX. are in a few cases not those actually recorded, but a corrected figure. For instance, the recorded drainage from the 20-inch gauge in February 1879 was 5·734 inches: this amount was greatly above that of the other gauges, and there being some evidence of leakage from the outside, the record has been rejected, and the amount passing through the 40-inch gauge substituted in its place. Again, in the tremendous rainfall of August 2–3, 1879, some of the receivers overflowed, and one was floated and disconnected by the rise of water in the chamber under the gauges. In this instance, and in some others of a somewhat similar kind, an estimated drainage deduced from a consideration of the amount of rainfall, and other facts of the case, has been adopted in place of the observed drainage, which was obviously incorrect. Another source of error has arisen from unequal drifts of snow on the surface of the three gauges. Thus, in April 1878, the recorded drainage through the 20-, 40-, and 60-inch gauges was respectively 2·249, 2·822, and 3·467 inches; but as the receivers of the 20-inch gauge ran over slightly, while a small snow-drift had occurred on the surface of the 40-inch gauge, and a heavy one on the surface of the 60-inch gauge, the figures for the month have been corrected; the record of the 20-inch gauge, where there was no drift, being adopted for the other gauges for those days of the month during which the thawing of the snow occurred. The records thus altered appear in the Table as 2·349, 2·524, and 2·428 inches respectively. In all cases in which the correction has been sufficiently large to become important, the figure in the Table will be found enclosed in a bracket.

In a few cases, as in November 1870, February 1879, and January 1880, the monthly drainage from some of the gauges has exceeded the monthly rainfall. Generally this has been more or less due to rain, or especially snow, falling at the end of one month and appearing as drainage in the next. It

* A summary of the results for the first five harvest-years (Sept. 1 to Aug. 31 inclusive) was given at a meeting of the Institution of Civil Engineers, Feb. 29, 1876, and is published, with a few comments, in the 'Minutes of Proceedings' of the Institution, vol. xlv., part iii.

occasionally happens also in severe winters that a considerable amount of frozen water is retained in the upper layer of the soil for some time, and appears as drainage only when a complete thaw takes place. There is, however, another possible explanation of excessive drainage in relation to rainfall, namely, the condensation of water by the soil directly from the atmosphere. That such condensation must take place whenever the temperature of the soil is below the dew-point of the atmosphere is quite plain.* During a clear frosty night both rain-gauge and soil will condense water from the atmosphere, and the soil, perhaps, somewhat the more. It seems, however, very probable that after a long-continued frost, followed by mild weather, the soil may continue for some time to condense from the air very appreciable quantities of water of which the rain-gauge will give no account. There is some evidence, which will be mentioned by-and-by, that such a condensation of water took place in the soils of the drain-gauges during the severe winters of 1878–9 and 1879–80. The total amount of water obtained by the soil from the atmosphere without the records of the rain-gauge being affected, is probably, however, save in exceptional seasons, not considerable. We shall have some evidence further on that the condensation by soil during the winter months is at all events no greater than the condensation by a water-surface.

Before discussing the results obtained in the drainage experiments, it will be well to consider briefly what takes place when rain falls upon a soil. It would be a mistake to regard an ordinary soil as a uniform porous mass, which simply becomes saturated with water, and then parts with its surplus by drainage; soil is, in fact, penetrated by innumerable small channels, and through these more or less of the drainage always takes place. Some of these channels consist of surface-cracks, which, becoming partly filled with sand and small stones, remain partially open after dry weather has ceased. The deeper channels are, however, not of this character, but are produced by the roots of plants, or to a still greater extent by the burrowing of worms. The soil drain-gauges we are now concerned with have furnished illustrations of both these actions. During the digging of the trenches round the gauges, barley-roots were observed penetrating the soil to a depth of 50 or 60 inches. When such roots decay, a small open channel is left through which drainage can take place. The burrowing of worms in the soil of the drain-gauges has proved a source of trouble in the collection of pure drainage-waters. Worms have not unfrequently

* A soil baked by a summer sun may re-absorb a certain amount of water from the air during the night without its temperature falling below that of the air; but the water thus absorbed is hygroscopic and will not appear as drainage.

TABLE XIX.—THE AMOUNTS of MONTHLY PERCOLATION through SOILS 20, 40, AND 60 INCHES DEEP.

MONTHS.	1870.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	Av. 10 yrs. 1871–80.
SOIL 20 INCHES DEEP.												
	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
January		0·254	3·641	2·769	1·216	2·871	1·463	3·793	1·101	2 470	0·482	2·006
February		0·913	0·641	0·708	0·850	0·341	1·874	0·869	1·013	[4·438]	2·360	1·401
March		0·337	0·920	0·884	0·009	0·499	1·283	1·014	0·273	0·138	0·038	0·540
April		0·811	0·089	..	0·319	0·085	[1·360]	1·327	2·349	1·270	0·493	0·810
May		0·002	0·778	..	..	0·290	0·003	0·445	1·479	1·217	0·002	0·422
June		1·294	0·769	..	..	0·349	..	0·026	0·611	2·156	0·010	0·521
July		0·809	0·006	0·625	[0·420]	3·292	..	0·560	0·009	1·828	1·352	0·890
August		0·002	0·018	..	..	0·001	0·146	0·384	1·331	[4·601]	0·214	0·670
September	0·216	1·821	0·004	0·704	0·634	0·890	2·296	0·205	0·075	1·110	3·964	1·170
October	1·070	0·118	3·134	0·992	1·525	3·715	0·823	0·580	1·370	0·221	4·466	1·694
November	1·839	0·069	2·854	1·080	1·209	3·238	2·886	4·031	3·771	0·195	2·244	2·158
December	2·094	0·818	3·375	0·156	1·155	0·785	5·212	1·742	1·108	0·413	2·814	1·758
Total	5·219	7·248	16·229	7·918	7·337	16·356	17·346	14·976	— 490 14·	20·057	18·439	14·040
SOIL 40 INCHES DEEP.												
January		1·124	3·552	2·729	1·358	3·385	1·758	4·411	1·362	2·652	0·611	2·294
[illegible]		1·186	0·771	0·544	0·842	0·442	2·204	1·191	1·208	4·438	2·591	1·586

September	0·063	1·424	0·017	0·378	0·249	0·829	2·236	0·254	0·122	0·996	3·981	1·044
October	0·453	0·240	2·677	0·835	1·258	3·950	1·097	0·505	1·391	0·422	4·448	1·682
November	1·421	0·144	2·806	1 109	1·045	3·541	2·991	4·201	4·067	0·116	2·387	2·241
December	1 950	0·759	3·402	0·111	1·840	[1·012]	5·741	1·982	1·874	0·490	2·852	1·906
Total	3·887	8·100	15·730	7·207	6·865	18·157	19·612	16·954	16·451	21·108	18·985	14·916

Soil 60 inches deep.

January		0·724	3·131	2·713	1·207	2·615	1·671	4·106	1·200	2·472	0·457	2·030
February		0·706	0·381	0·550	0·735	0·381	1·944	1·233	1·132	4·216	2 301	1·378
March		0·231	0·829	0·802	0·034	0·462	1·565	1·105	0·458	0·257	0·085	0·585
April		0·633	0·127	0·005	0·248	0·062	[1·720]	1·486	[2·428]	1·375	0·434	0·852
May		0·035	0·629	..	..	0·304	0·028	0·510	1·502	1·297	0·028	0·438
June		0·898	0·764	..	..	0 140	..	0·102	0·755	2·185	0 020	0·486
July		0·600	0·016	0·372	[0·334]	3·346	..	0 440	0·063	1·806	1·062	0·804
August		0·002	0·027	0·001	..	0 030	0·025	0·318	1·129	[4·346]	0·221	0·609
September	0·018	1·077	0·011	0·200	0·212	0·707	2·041	0·207	0·113	0·920	3·779	0·927
October	0·183	0·229	2·098	0·290	1·024	3·551	0·955	0·389	1·103	0·426	4·070	1·414
November	0·705	0·349	2·498	0·859	0·687	3·265	2·660	3·824	3·665	0·090	2·141	1·999
December	1·072	0·479	3·046	0·039	1·039	[0·972]	5·252	1·752	1·542	0·412	2·681	1·724
Total	1·978	5·963	13·697	5·881	5·520	15·835	17·881	15·467	15·090	19·843	17·279	13·241

appeared on the collecting funnel of the 20-inch gauge, having come through the soil above; and what appear to be worm-casts, dropped from the holes of the perforated iron plates, are of still more frequent occurrence. Worms have also appeared, though much more rarely, on the collecting funnels of the 40- and 60-inch gauges. The holes made by worms thus descend to a considerable depth, and if sufficiently numerous, must have an important influence on drainage.

The drainage-water from a soil may thus be of two kinds: it may consist (1) of rain-water which has passed, with but little alteration in composition, down the open channels of the soil; or (2) of the water discharged from the pores of a saturated soil. This latter water, the true drainage of the soil, will itself escape to a greater or less extent through the channels already mentioned. The respective proportions of *direct* and *general* drainage will vary much in different soils, and under different circumstances. In a light soil, of naturally free drainage, channels can play but an insignificant part, the rain being at once absorbed by the main body of the soil, and freely discharged again from its pores when saturated. In heavy soils, on the other hand, both the absorption and the discharge of water can take place but slowly, and the part which natural channels play in freeing the soil of water is more considerable. In a heavy soil direct channel-drainage will in most cases precede general drainage, a portion of the water escaping by the open channels before the body of the soil has become saturated; this will especially be the case if the rain fall rapidly, and water accumulates on the surface. When the soil is saturated, general drainage will become active. After rain has ceased, and the surface is free from standing water, the drainage which occurs will be entirely due to the general discharge from the saturated soil. The two kinds of drainage-water here mentioned differ much in composition, the direct channel-drainage containing a much smaller proportion of soluble salts than is found in the true discharge from the soil. This difference in composition has been very frequently exemplified in the analyses of the Rothamsted drainage-waters, and has enabled us to trace the distinction between these two classes of drainage-water.

When rain has ceased, and a period of dry weather occurs, water will begin to evaporate from the surface of the soil; the water in the subsoil will be gradually drawn up by capillary attraction as the surface dries, and be itself in turn evaporated. The depth to which the subsoil will be dried by this loss of water through capillary attraction will depend on the mechanical texture of the soil; the depth will be greater in the case of a loam or clay than in the case of a soil of more open

re, the height to which water can be raised by capillary tion being in proportion to the fineness of the spaces gh which it passes.

is obvious that in the case of a soil like that at Rotham- having a subsoil of clay not many feet in depth, resting chalk tending constantly to drain it, the conditions affect- the discharge of water from the land within a limited from the surface will be in the main very different from occurring in a soil having a considerable depth of re- re clay. In the former case, the discharge within, or not elow, the usual limits of artificial drainage, will in a much er degree depend on the direct downward passage of water, much less on the raising of the point of saturation from r. It is further obvious that in a soil so naturally drained, reater the amount of rainfall in a given season, the greater be the depth to which a given amount of water will pass, in a season of smaller rainfall the depth of penetration will ss. We should expect, therefore, that in a dry season the lation would be greater through 20 than through 40, and er through 40 than through 60 inches of soil. In a wet season, e other hand, the amount of percolation would be relatively ased at the lower depths, and would tend towards equality. would be the case if no interfering circumstances were rted into the question by the fact of absolutely cutting off locks of soil at different depths, thereby preventing the bility of capillary attraction acting and water returning rds from below the point at which the cutting off had place. Another consequence of this cutting off would be use a more complete drying of the soil of the drain-guage ches deep during dry periods than of that to a correspond- depth in the deeper gauges. The shallower soil would fore require more water to saturate it to the same depth subsequent rains came, and hence the amount of water lating through it would be less than would otherwise be the It must also be borne in mind that the total amounts of retained by the different thicknesses of soil would be very ent, and would vary in relation to one another at different . It is to be regretted that our data do not enable us to ate accurately the influence of these various circumstances. rtunately, too, the results obtained by the experimental -gauges of different depths are somewhat anomalous, and as do not seem capable of satisfactory explanation by the f the various considerations above referred to.

n looking at Table XIX. it will be seen that up to the of 1874, the drainage from the 40-inch gauge was on the e somewhat less than that from the 20-inch gauge, and that

from the 60-inch gauge was distinctly less than that from the 40-inch gauge. In November and December 1874 the walls surrounding the experimental soils were, as already mentioned, covered externally with cement, and then thickened by an additional half-brick. Since this time the relative proportions of the drainage from the three gauges have been different. The 40-inch gauge has given on an average considerably more drainage-water than the 20-inch gauge, while the 60-inch gauge has given much less than the 40-inch, and nearly the same quantity as the 20-inch gauge. The exact state of matters during the two periods of the experiment will be seen from the following Table (XX.):—

TABLE XX.—The AVERAGE ANNUAL RAINFALL and DRAINAGE through 20, 40, and 60 INCHES of SOIL, during the PERIODS 1871–74, 1875–80, and 1871–80.

	Rainfall.	Drainage in Inches.			Drainage for 100 Rainfall.		
	Inches.	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.
Four Years, 1871–74	27·344	9·683	9·476	7·753	35·4	34·7	[illegible]
Six „ 1875–80	34·189	16·944	18·544	16·899	49·6	54·2	[illegible]
Ten „ 1871–80	31·451	14·040	14·916	13·241	44·6	47·4	[illegible]

On looking at the column for rainfall it will be observed that the last six years have been much wetter than the preceding four. We expect therefore to find a greater divergence between the amounts of drainage from the three gauges during the first four years than during the last six. The considerable increase of rainfall in the latter period thus helps to explain the near approachment of the drainage from the 20-inch and 60-inch gauges during this time, but it fails to explain the fact that the 40-inch gauge has during the same period furnished so much more drainage than either of the others. As these differences do not seem to be adequately explained by the considerations above referred to, we must either assume some defect in the 20-inch gauge, leading to a leakage outwards, and resulting in a deficient drainage, or some defect in the 40-inch and 60-inch gauges, leading to an increased, and in the case of the 40-inch gauge to an excessive drainage. In regard to these points it should be stated that the only really known leakage was in the 20-inch gauge, already referred to as occurring in February 1879; but this leakage was from the outside inwards,

reas it must be a leakage from the inside outwards that ld help to explain the discrepancies in question. The ent relatively excessive drainage of the 40-inch gauge is confined to wet seasons, though it is then greatest, but it ears also in dry years, and even during the spring and mer months. Thus the average drainage from March to ust during the last six years was respectively 5·07, 5·68, 5·18 inches for the three drain-gauges.

n a consideration of all the facts it would seem that the nage from the 40-inch gauge has been relatively somewhat ssive during the last six years; the excess is however less ked at present than it was two or three years ago. The unt of drainage from the 60-inch gauge has also apparently n in some excess, but in a less degree, during the same period. *excessive* drainage can clearly only occur by leakage of er from the outside through some defect in the walls. It is lent that from the position of the 40-inch gauge there may t times a greater pressure of water on two of its sides than e is within the gauge, due to the sloping edges of the walls ounding the gauges delivering an excessive amount of rain o the two thin bands of soil which separate the gauges (see 2), and the thickening of the walls, which took place towards end of 1874, would increase this side pressure. It must rankly confessed, however, that it is difficult to believe that age would be more marked after the thickening and cement- of the external walls than it was before.

lotwithstanding the difference in the relation of the gauges ifferent periods of the experiment, it is pretty clear that at all s evaporation has been somewhat greater in a dry season n the soil of the 60-inch gauge than from the soil of the nch gauge, and that consequently capillary attraction has ed capable of bringing water to the surface from a depth eding 20 inches. The excess of evaporation on the 60-inch ge is, however, at present very small. Thus, during the est year beginning September 1, 1879, and ending ust 31, 1880, the rainfall was 21·358 inches, the season g the driest corresponding period in the past ten years. drainage during these twelve months amounted to 6·890 es from the 20-inch gauge, to 7·393 inches from the 40-inch, to 6·495 inches from the 60-inch gauge; the excess of oration on the 60-inch over that on the 20-inch gauge was only 0·395 inch.

aving now disposed of the preliminary questions belonging he subject, we may proceed to consider the general facts ibited by the ten years' drainage experiments.

n the following Table (p. 40) the rainfall and drainage of

TABLE XXI.—The AMOUNTS of RAINFALL, DRAINAGE, and EVAPORATION for the TEN SUMMERS, WINTERS, and DRAINAGE-YEARS, during the PERIOD 1870–80 (DRAINAGE MEAN of 20, 40, and 60 INCH GAUGES).

Summer: April—September				Winter: October—March.				Drainage-Year: October—September.			
Season	Rainfall	Drainage	Evaporation.	Season	Rainfall	Drainage.	Evaporation	Season.	Rainfall	Drainage.	Evaporation.
1873	11·633	0·923	10·710	1879–80	7·031	3·048	3·083	1873–4	22·937	4·970	17·967
1874	13·097	1·052	12·045	1873–4	9·840	3·918	5·922	1879–80	24·087	9·808	14·279
1872	14·147	1·645	12·502	1871–2	12·165	6·032	6·133	1871–2	26·312	7·677	18·635
1877	14·429	3·139	11·290	1870–1	12·768	5·546	7·222	1870–1	29·317	9·631	19·686
1876	14·921	3·898	11·023	1874–5	13·407	7·281	6·126	1874–5	30·791	12·200	18·591
1871	16·549	4·085	12·464	1877–8	13·919	9·084	4·835	1872–3	31·620	13·772	17·848
1880	17·056	5·860	11·196	1878–9	16·964	13·586	3·378	1877–8	32·586	15·216	17·370
1875	17·384	4·919	12·465	1875–6	19·280	13·185	6·095	1875–6	34·201	17·083	17·118
1878	18·667	6·132	12·535	1872–3	19·987	12·849	7·138	1876–7	35·793	18·669	17·124
1879	25·754	12·271	13·483	1876–7	21·364	15·530	5·834	1878–9	42·718	25·857	16·861
Mean..	16·364	4·393	11·971	Mean..	14·073	9·096	5·577	Mean..	31·036	13·489	17·548

ı of the summer and winter periods during the past ten years shown; the rainfall and drainage for each twelve months—ober 1 to September 30—are also given. This period of lve months we may, for our present purpose, call the 'rainage Year;" and our mode of record will thus agree h the division into Civil-year periods adopted by Mr. Greaves . Mr. Evans. The whole of the seasons are arranged in the le in the order of their respective rainfall; the influence of ying amounts of rain is thus clearly shown. The amounts lrainage given are the mean of the results yielded by the e drain-gauges, 20, 40, and 60 inches in depth.

'he range of rainfall during the ten years of the experiment een to have been enormous. We have a consecutive twelve ıths with a rainfall of 22·937 inches, and another similar od with a fall of 42·718 inches. In the six winter months range of rainfall has been still greater, namely from 7·031 to 364 inches. The ten years of experiment have thus afforded mples of extreme rainfall and drought, such as are usually r found in much longer periods of observation.

Vith this very large variation in the rainfall we have a yet ıter variation in the amount of water passing through the . The summer drainage is seen to vary from 0·923 to 271 inches; the winter drainage from 3·918 to 15·530 ıes; and the drainage of the whole drainage-year from 70 to 25·857 inches. Expressed in percentages of the rain-the drainage in summer has varied from 7·9 to 47·6, with ıean of 26·8 per cent.; the drainage in winter from 39·8 80·1, with a mean of 61·9 per cent.; and the drainage the whole year from 21·7 to 60·5, with a mean of 43·4 cent.

'o understand the cause of this extreme variation in the 'unt of water passing through the soil we must turn our ation to the amount of evaporation from the surface which at the same time taken place, and which is also shown in table. The amounts of evaporation during each season have ı ascertained by simply subtracting the amount of drainage ı the amount of rainfall. That portion of the rainfall which not appear as drainage-water has clearly been returned to ıtmosphere by evaporation; this is true, at all events, when soil holds a similar amount of water at the beginning of the period of the experiment. That the soil of the drain-ges was actually in a similar state of dryness at the beginning end of every period mentioned in the table is by no means cted; the figures representing the evaporation are thus aps seldom quite exact, and in a few cases are certainly rror. The error is, however, usually small, as at the com-

mencement and end of the periods chosen (October 1 and April 1) the soil will generally contain a moderate, but not excessive, amount of water. In the mean evaporations for summer and winter, given at the foot of the table, the error just mentioned will be but small; and in the mean evaporation for the whole year probably *nil.*

The amount of evaporation taking place from a bare uncropped soil will depend on the temperature of the soil, the temperature and dryness of the air, and the amount of wind, and also on the amount and distribution of the rain: the amount of evaporation is, in fact, limited not only by the conditions as to heat, wind, &c., but also by the amount of water available on the surface.

The distribution of the rain has a considerable influence on the amount of evaporation; a heavy rainfall occurring in a few days will always result in more drainage and less evaporation than the same quantity of rain distributed over a month; and to this cause some of the variations in drainage with a similar rainfall, to be found in Table XXI., are plainly due. In the Rothamsted drain-gauges, however, containing as they do a heavy soil in its natural condition of consolidation, and with its clay subsoil untouched, the differences in the amount of drainage due to irregularities in the distribution of the rain are far smaller than those which have been observed by others employing small percolators more or less loosely filled with porous soil, and generally with growing turf upon the surface.

Turning now to the figures of the table, we see that the amount of evaporation from the soil during the whole drainage-year appears, with two marked exceptions, to be a fairly constant quantity. The whole range of evaporation in ten years is from 14·279 to 19·686 inches; but excluding these extremes, the variation in eight years is only from 16·861 to 18·685 inches. That in years of very different rainfall the soil has evaporated almost the same amounts of water, is strikingly shown by many of the results, as for instance those for 1873–4, 1872–3, and 1876–7.

The large amount of evaporation credited to the year 1870–71, is probably due to an error in estimation of the kind already noticed. The drain-gauges were constructed during the exceedingly dry summer of 1870, and the blocks of soil to be included in the gauge having been isolated by trenches cut round them, were necessarily more or less exposed to air on all their sides; the soil was thus dried to an unusual extent, and when rain commenced a considerable amount was consumed in wetting the soil before drainage took place. Under these circumstances it is clear that a part of the rain credited to [illegible]

really retained by the dry soil, the true evaporation uently distinctly below the estimated quantity.

emely low evaporation of the year 1879–80, and the result for 1878–9, are chiefly owing to the abnormal is calculated for the winters of these years, the cause ill be presently considered.

unts of evaporation for the summer half of the year y considerable uniformity, notwithstanding great in the rainfall. During ten summers the smallest has been 10·710, and the largest 13·483 * inches. these extremes, the variation in eight years has been 1·023 to 12·535 inches.

nparative constancy of the evaporation under very nditions of climate is certainly remarkable; it must due to the fact that the two principal conditions rmine a large evaporation, namely excessive heat nt rain, very rarely occur together. In a wet season, oil is kept well supplied with water, there is at the a more or less saturated atmosphere, with an absence , conditions unfavourable to a considerable evapora- hot season there is, on the other hand, usually a rain; and after the surface of the soil has dried must proceed very slowly.

res representing the evaporation from the soil during half of the year are by no means so regular as those the summer half, or to the whole year. This is to the small amount of the evaporation, which is therefore, considerably affected by any disturbing nearer study of the results shows, however, that the is considerably more constant than at first appears. 70–1 and in 1872–3 the high calculated figure for is certainly in excess of the truth; in each case the nusually dry just before the commencement of the iod, and in the latter winter it was also some- ally wet at the end of this period: rain has thus ned as evaporation which really was simply retained Errors of reckoning of this description are natu- r in the case of the deeper drain-gauges, and least in the 20-inch gauge. With this gauge the range of tion calculated for the winter months is much smaller

* ulated figure is undoubtedly rather higher than the true evapora- mmer six months succeeded a dry March and concluded with ber, nearly 1 inch of rain falling in the last three days of this drainage is thus from two causes somewhat below the amount nging to the rainfall, and the calculated evaporation is to the same h.

than with the other gauges; omitting 1878–9 and 1879–80, the range with this gauge is but from 5·182 to 6·924 inches.

The winters of 1878–9 and 1879–80 show a remarkably small calculated evaporation, and considerably diminish the total evaporation of the years of which they form part. The winter of 1879–80 is the most striking of these exceptions; it succeeded the wettest summer in the whole ten years, while the winter itself was the driest and coldest in the same period. The rainfall of October and January being insufficient to provide for a normal evaporation, and the low temperature tending also to a reduced rate of evaporation, we should expect the amount of evaporation during this winter to be somewhat below the average. A more potent cause of the extremely low figure found by calculation is, however, the abnormally high drainage. The soil commenced October in a saturated condition, while the winter concluded with a fairly dry March; a part of the winter drainage thus belonged to the summer rainfall—a most unusual circumstance. The very exceptional high rate of drainage during January and February cannot, however, be explained by reference to the previous summer's rainfall, and certainly points to an actual condensation of water by the soil, probably occurring at the close of the severe frost experienced during those months.

The winter of 1878–9 was not quite so exceptional as the one last mentioned. It followed a wet summer, and concluded with a dry March, the temperature was also nearly as low as in the winter of 1879–80; some of the circumstances tending to produce a low evaporation and high drainage were thus the same in both seasons, though not so marked in 1878–9 as in 1879–80. The evidence of condensation of water by the soil during January and February was, however, still more distinct during the winter now under consideration, the drainage of January and February being far above the normal proportion to the rainfall.

We conclude, therefore, that these winters had probably a rate of evaporation rather below the average; but the serious deficiency shown by the figures in the table had probably no existence, being simply due to a special increase of the drainage from sources independent of the rainfall of the period.

We now turn to the average amounts of evaporation for each season given at the foot of Table XXI. The rate of evaporation having altered, on the whole, within moderate limits during the last ten years, these figures will express with tolerable accuracy the amount of evaporation which will ordinarily take place from the Rothamsted soil when kept bare of vegetation, in a climate having a mean temperature of about 48°. The average amount of evaporation during the six [illegible]

arly 12 inches, during the six winter months about 5½ inches, d for the whole year 17 to 18 inches.

We have dwelt thus at length on the amount of evaporation from e soil of the drain-gauges because the *comparative* constancy of e evaporation from the surface of a bare clayey soil in seasons very different character is a fact probably not generally re- gnised, and because this comparative constancy in the amount evaporation is, in the case of our drain-gauges, the law which etermines in the long run the amount of drainage. Drainage is fact merely the *excess of rainfall over evaporation.* With this ew of drainage in our minds, the cause of the great variation in amount becomes readily understood; for we may almost say at up to the point at which the rainfall equals the evaporation the season no drainage will take place, but that beyond that int every inch of rain will produce an inch of drainage- ter. This general statement assumes of course ordinary and extraordinary conditions, and it is true of long periods her than short ones; in short periods the immediate distribu- of the rain will certainly have a preponderating effect. e cause of the immense excess of winter over summer drain- becomes now apparent. The rainfall in summer is actually excess of that in winter, but the drainage during the summer nths is only half that experienced in winter, owing to the far ater amount of evaporation during the warmer half of the year.

As to the various rates of evaporation from soils of different ths, the drain-gauges unfortunately give, as we have already n, no certain information. The average evaporation from the 40, and 60-inch gauges are separately given at the foot of ble XXII. (p. 46); the figures we have discussed have been ll cases a mean of the three results. With soils more open n that at Rothamsted, of less water-holding capacity, and of er capillary power, the amount of evaporation will be much , and the proportion of the rainfall which appears as drainage greater. The amount of evaporation in such soils is also re variable, the surface possessing no regular supply of water. e behaviour of soils of this description is shown in an ex- gerated manner by Mr. Greaves's experiment on a mass of re sand, the general results of which will be found in Table XV. (p. 53). On the other hand, with soils of greater water- lding power, or with a heavier summer rainfall, the amount evaporation during the summer months, and consequently the whole year, might be somewhat increased; but the ssible range of variation in this direction is not large, as r. Greaves has shown that the average annual evaporation m a water surface is but 20·658 inches, or only about 3 inches eater than that obtained from the Rothamsted soil.

To complete our view of the results yielded by the drain-gauges we must now proceed a step further, and see what has been the average amount of drainage and evaporation for each month in the year.

It appears from Table XXII. that drainage has on an average

TABLE XXII.—The AVERAGE MONTHLY RAINFALL, with the AVERAGE MONTHLY PERCOLATION and EVAPORATION from SOIL 20, 40, and 60 INCHES in DEPTH, during 10 YEARS, 1871–80.

	Rainfall.	Drainage.			Evaporation.		
		Soil 20 inches deep.	Soil 40 inches deep.	Soil 60 inches deep.	Soil 20 inches deep.	Soil 40 inches deep.	Soil 60 inches deep.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
January	2·802	2·006	2·294	[illegible]	0·796	0·508	[illegible]
February ..	2·100	1·401	1·536	1·378	0·699	0·564	[illegible]
March	1·595	0·540	0·675	0·585	1·055	0·920	[illegible]
April	2·398	0·810	[illegible]	[illegible]	1·588	1·477	[illegible]
May	2·224	0·422	0·501	0·433	1·802	1·723	[illegible]
June	2·663	0·521	0·535	0·486	2·142	2·128	[illegible]
July	3·280	0·890	0·918	0·804	2·390	2·362	[illegible]
August* ..	2·677	0·670	0·663	0·609	2·007	2·014	[illegible]
September ..	3·123	1·170	1·044	0·627	1·953	2·079	[illegible]
October ..	3·162	1·694	1·682	1·414	1·468	1·480	[illegible]
November ..	3·094	2·158	2·241	1·999	0·936	0·853	[illegible]
December ..	2·333	1·758	1·906	[illegible]	0·575	0·427	[illegible]
Whole Year	31·451	14·040	14·916	[illegible]	17·411	16·535	[illegible]

commenced in earnest in September, and remained at a high point till March, that is, during the periods usually designated as "Autumn" and "Winter"; the maximum drainage being reached in November or January. From March to August ("Spring" and "Summer") the drainage has been comparatively small, the minimum having occurred in May. In considering these figures it must, however, be borne in mind that the rainfall during the ten years of the drainage experiments has been singularly abnormal; not only has the annual fall been excessive (about 3 inches above the average), but the distribution has been irregular, certain months having been specially affected. If we assume, as we fairly may, that the amounts of monthly evaporation ascertained for the past ten years would remain nearly the same under a normal rainfall, it becomes possible by simply subtracting the excess, or adding the deficiency of the rainfall, to calculate what would be approximately the monthly

* Excluding the very exceptional rainfall and drainage of August 1879, the average drainage for the month would be only about [illegible] as much as the figures show.

ıge under a rainfall of average amount. The results of ı calculation will be found in Table XXIII.

: XXIII.—Calculated Average Monthly Drainage from ıl 20, 40, and 60 inches in depth, when Rainfall is of Normal ıantity.

	Rainfall.		Rain of 10 Years under or above Rain of 28 Years.	Drainage, assuming normal Rain.		
	Average 28 Years, 1853–80.	Average 10 Years, 1871–80.		Soil 20 inches deep.	Soil 40 inches deep.	Soil 60 inches deep.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
ıuary	2·590	2·802	+0·212	1·794	2·082	1·818
bruary ..	1·728	2·100	+0·372	1·029	1·164	1·006
ırch	1·693	1·595	−0·098	0·638	0·773	0·683
ril	2·008	2·398	+0·390	0·420	0·531	0·462
ıy..	2·329	2·224	−0·105	0·527	0·606	0·538
ne	2·451	2·663	+0·212	0·309	0·323	0·274
ly..	2·704	3·280	+0·576	0·314	0·342	0·228
gust	2·643	2·677	+0·034	0·636	0·629	0·575
ptember ..	2·638	3·123	+0·485	0·685	0·559	0·442
tober	3·089	3·162	+0·073	1·621	1·609	1·341
ıvember ..	2·345	3·094	+0·749	1·409	1·492	1·250
cember ..	2·084	2·333	+0·249	1·509	1·657	1·475
hole Year ..	28·302	31·451	+3·149	10·891	11·767	10·092

ıhould be stated that in the construction of this artificial e (XXIII.), exceptional rainfalls and drainage, such as of August 1879, are not excluded. The figures as they would indicate that under a normal rainfall considerable age would not set in before October, and would continue : end of February, the maximum drainage being in January. ı March to the end of September the amount of drainage nparatively small, the minimum being reached in June and If these indications should prove to be correct, the al drainage year of this uncropped land would commence October, the first autumn month in which a great fall of erature occurs, and also the month of maximum rainfall.

e must now glance at the average amounts of evaporation ıg each month, which have been given in Table XXII. ing first at the results obtained with the 20-inch drain- e we see that evaporation from the soil takes place to the lest extent in December. In January it is slightly greater, ımaller supply of radiant heat during the short days of ımber checking evaporation apparently more than the lower ımperature of January. In February evaporation remains altered, but in March a decided rise commences, continuing lily up to July, when the maximum rate of evaporation is

attained; from this point a decline sets in till the minimum is once more reached in December.

The amount of water evaporated per month is not always, however, exactly shown by the mode of calculation we are forced to adopt. We have already frequently called attention to the error which must occur in our calculations when the soil is drier or wetter at the end of the experimental period than it was at the beginning. This source of error only occasionally affects the correctness of our calculations when the period in question is a long one, or when the average of many similar periods can be obtained in which it is an equal chance whether the soil is drier or wetter at the end than at the beginning, but it certainly distinctly affects a portion of the monthly averages. The amounts of evaporation calculated for the mid-winter months will be practically free from errors of this description, if the average of a sufficient number of years be taken. From winter, however, to the height of summer, the soil must generally tend to become drier, and the calculated evaporation for the months lying in this period will consequently be on the whole too low. The hottest season passed, a reverse action will take place, the soil gradually becoming more saturated with water; the figures given as representing evaporation during this portion of the year will therefore be too high. A comparison of the amounts of evaporation calculated for the Rothamsted soil with the average monthly evaporation determined by Mr. Greaves for a water-surface (see Table XXV., p. 53) is most instructive, and shows very clearly the existence of the two errors in opposite directions which affect our calculations for spring and autumn.

During December, January, February and March, the amounts of evaporation from a water-surface are seen to be all but identical with the evaporation calculated for the soil of the 20-inch gauge at Rothamsted, plainly showing that the soil is during these months sufficiently saturated with water to yield at all times a maximum rate of evaporation. During the warmer months of the year we should expect to find the evaporation from the water uniformly greater than from the soil, as the soil is not at this time of the year permanently saturated. We find, however, that while the evaporation from a water-surface considerably exceeds that from the soil from April to August, the evaporation from the soil is distinctly greater during September, October and November, the difference in favour of the soil during these months amounting on the whole to 1 inch. Under spring and autumn seasons of similar temperature we find, therefore, that in the spring the evaporation from water exceeds that calculated for the soil, while in autumn the converse holds true. This is quite in accordance with our previous reasoning. There can be little

oubt that the evaporation credited to the soil for September and 'ctober is somewhat too high, while that reckoned for April and .ay is rather too low.

On comparing the records of the 20, 40, and 60-inch gauges ven in Table XXII. (p. 46), it is evident that the relation 'tween them is different at different times of the year. In the ring months drainage will continue to take place from the ver layers of a deep soil when it has altogether ceased in a illower soil. In summer and autumn, on the other hand, the inage will be less from the deeper soil, as there is in this e a larger mass of dry soil to be saturated with water before inage can commence. In March and April the drainage n the soil 40 and 60 inches in depth, is on an average ier greater than that from similar soil 20 inches deep; but August, September, and October, the relation is reversed, the llowest soil yielding the largest drainage. These facts ear in the records of the gauges for the last six years, as l as in the records for the first four years; the extent of erence is, however, much less in the later years. It clearly ows from these facts that the errors affecting the calculated ount of evaporation from the soil during the spring and umn months will be greatest in the case of the deeper soils, l that the calculations made on the results of the 20-inch ige will most nearly represent the truth.

n a table on the following page the average monthly drainage n the three gauges is given as percentages of the rainfall; in same table will be found the percentage relation of the umed normal drainage (see Table XXIII., p. 47) to the mal rainfall, the average of twenty-eight years.

These figures will require no explanation. The average per-tages of drainage to rainfall during summer and winter have n already given (page 41). The mean annual proportion drainage to rainfall there given is not exactly the same as the present table, the former results being the mean of ten inage-years, and the latter of ten civil years.

f we may assume a comparatively constant annual evapora-n from the surface of the soil, it becomes possible to calculate roximately the percentage of drainage to rainfall for any en rainfall distinctly exceeding the amount of evaporation. us assuming 17·5 inches as the annual amount of evapora-n, then with a rainfall of 28·3 inches (the present average at thamsted), the drainage will amount to about 38 per cent. ith a rainfall of 25 inches, the drainage would in like manner 30 per cent. With a rainfall of 20 inches, 12·5 per cent.

It must be carefully borne in mind that the whole of the facts d figures hitherto given relating to drainage and evaporation

TABLE XXIV.—AVERAGE MONTHLY DRAINAGE for 100 RAINFALL during 10 YEARS, 1871–80. Also the DRAINAGE for 100 RAINFALL with assumed normal quantities of both.

	Observed Drainage for 100 Rainfall.			Assumed Normal Drainage for 100 Normal Rainfall.		
	Soil 20 inches deep.	Soil 40 inches deep.	Soil 60 inches deep.	Soil 20 inches deep.	Soil 40 inches deep.	Soil 60 inches deep.
January	71·6	81·9	72·4	68·3	80·4	70·2
February ..	66·7	78·1	65·6	59·5	67·4	58·2
March	33·8	42·3	36·6	37·7	45·7	40·3
April	33·8	33·4	35·5	20·9	26·4	23·0
May..	19·0	22·6	19·5	22·6	26·0	23·1
June	19·6	20·1	18·8	13·6	15·2	11·2
July	27·1	28·0	24·5	11·6	13·6	9·4
August	25·0	24·8	22·8	24·1	29·8	21·8
September ..	37·5	33·4	29·7	26·0	21·2	16·7
October	53·6	53·2	44·7	52·5	52·1	42·4
November ..	69·7	72·4	64·6	60·1	68·7	59·8
December ..	75·3	81·7	73·9	72·4	79·6	76·0
Whole Year ..	44·6	47·4	42·1	36·5	41·6	35·7

have reference to a soil entirely bare of vegetation, and consequently are only partially applicable to ordinary land which is always more or less covered with vegetable growth.

We have now gone through the principal facts which the amounts of percolation from the three drain-gauges appear to teach. That experiments with soils kept bare of vegetation can only touch a part of the questions connected with practical agriculture is obvious. A series of percolation experiments in which the influence both of crop and manure on the amount and composition of the drainage-water might be studied, was planned many years ago, but has not been brought to a successful issue. Eighteen cylinders made of stone-ware pottery, each 5 feet in depth and 2 feet in diameter, were sunk in the ground nearly to their upper edge. It was intended that these cylinders should be filled with soil similar in kind to that forming the three drain-gauges. Crops would then have been grown, and manures applied, the drainage-water passing through the soil collected and measured, and its composition determined by analysis. The substances applied as manure, and removed in the crop and drainage-water, being thus known, it was hoped that valuable information would be obtained on many important questions. Unfortunately the cylinders were found to leak. It also proved impossible to get into them the amount of soil necessary to obtain the same degree of consolidation as in the undisturbed field-soil, although,

as poured through, and a pressure exceeding one ton was in me cases applied. No further steps have yet been taken.

Several investigations have been made at Rothamsted on subject of the evaporation of water by plants, both when wn in pots* and in the field. In a paper published in the urnal of the Royal Agricultural Society' in 1871 (page 91), culations are given as to the amount of water removed from soil by certain crops during the hot and dry summer of 70, the calculations being based on actual determinations the amount of water remaining in the soil after the re- val of the crops. Thus it was shown that a crop of manured of 29½ cwts. had removed from the soil at least 2 inches, another manured crop of 56¼ cwts. at least 3·2 inches re water than an unmanured crop of 5¾ cwts. In the case a crop of barley grown on the same field in which the drain- ages were afterwards established, the crop had apparently noved from the soil about 9 inches more water than had eva- rated from the adjoining bare fallow; the conditions of the periment were, however, not all that could be desired.

The powerful action of a crop in evaporating water from a l is mainly due to the rapid transpiration of water through the ves, which takes place in a growing plant under the influence light; the roots also lend important assistance by enabling plant to draw water from depths of the soil too great to be turbed by ordinary capillary attraction. A deeply rooted crop y thus be more effective in drying the soil than a crop with allow roots, as is plainly seen by a comparison of the results oduced by the grass and barley-crops already mentioned.

As the transpiration of water in a plant is determined by ht, the amount of transpiration must have some connection th the rate of assimilation and growth. When the supply of ter and of soluble plant-food is tolerably constant, the rela- n between transpiration and growth will be fairly regular. om experiments made at Rothamsted many years ago, with ants grown in pots, it was concluded that from 250 to 300 lbs. water were evaporated for 1 lb. of dry matter added to the ant. It may be, however, that in a soil poor in soluble plant- od a larger amount of water would pass through the crop to eld the same amount of assimilation than in the case of a soil ell manured. The relation between transpiration and assimila- n will, indeed, probably differ under different circumstances.

The annual evaporation from a cropped soil can never be ckoned as a constant quantity, even under a uniform course of

* "Experimental Investigation into the Amount of Water given off by Plants ring their Growth, especially in relation to the fixation and source of their rious constituents."—Jour. Hort. Soc. Lond. v. 38. 1850.

cropping, as the character of the season will greatly affect the growth of the crop, and consequently its evaporating power. The evaporating power of a crop is also so often above the actual rainfall of the period of its active growth, that it is only occasionally that the full extent of this power is manifested.

We must now conclude this section with a word regarding the results of others in this branch of inquiry.

Dr. Dalton, as far back as 1796, constructed a percolation-gauge, consisting of a cylinder 3 feet deep, filled with soil, and sunk in the ground to the level of its upper edge, arrangements being made for collecting and measuring the water which passed through. This mode of experimenting has been adopted by many observers, as M. Maurice, M. Gasparin, Messrs. Dickinson and Evans, Mr. Greaves, Prof. Ebermayer, &c.* It is obvious that on this plan the soil forming the drain-gauge is more loose and open in texture than the natural consolidated soil of a field, thus admitting a freer percolation; pains also have seldom been taken to include the natural subsoil in the percolation-cylinder, which has generally been filled entirely with a surface soil. The surface of the gauge has again not been interfered with, and has speedily become covered by a mass of grass and weeds. The evaporation is of course greatly increased by the presence of this vegetation. Dr. Sturtevant, of Massachusetts, instead of using the Dalton gauge, had a wooden frame driven into the ground to the desired depth, thus enclosing the soil and subsoil in their natural condition. Of the results obtained by the Dalton gauges by far the most extensive are those by the late Mr. Dickinson, of Nash Mills, Hemel Hempstead, Herts, commencing in 1836,† and latterly continued by Mr. John Evans; and those commenced by Mr. C. Greaves at Lee Bridge in 1851, and carried on to the present time. We shall refer to the results of these experimenters in some little detail, as they excellently illustrate the influence of a crop on percolation and evaporation.

Messrs. Dickinson and Evans have employed two drain-gauges, consisting of cast-iron cylinders 3 feet in depth, and 18 inches in diameter; one is filled with the surface soil of the neighbourhood, the other with fragments of chalk; both bear a growth of grass. Mr. Greaves's drain-gauges consist of two square boxes made of slate, 3 feet in depth and 3 feet square;

* A brief notice of the results of Maurice, Gasparin, Ebermayer, and others, with a summary of those obtained at Rothamsted up to that date, will be found in the Minutes of Proceedings of the Institution of Civil Engineers, Session 1875-6, vol. XLV. part iii.

† The results for the first eight years will be found in the volume of the 'Journal of the Royal Agricultural Society' for 1845, page 150.

:hese is filled with sand (such as is employed for filter- ıssing through a screen of 33 No. 10 wires in 6 inches) n 2 inches of the top; the other with a mixture of soft :avel and sand, trodden in and turfed. Mr. Greaves has auge for measuring the evaporation from a water-surface, ng of a tank 1 foot in depth, and having an area of e yard; this tank is kept afloat in a flowing stream. ık contains a few inches of water, the rise or fall in s ascertained from time to time. This is probably the :curate method of determining the rate of evaporation ıter yet adopted. The figures we shall quote are taken o papers read by Mr. Greaves and Mr. Evans before the ion of Civil Engineers, February 29, 1876; these supply the results of Mr. Greaves for fourteen years—1860–73, ›se of Mr. Evans for fifteen drainage-years—1860–1 to The following Table gives a summary of Mr. 's results:—

XXV.—Mr. Greaves's Results respecting Drainage and Evaporation, average of 14 Years, 1860–73.

	Rainfall.	Drainage.		Evaporation.		
		Sand.	Turfed Soil.	Sand.	Turfed Soil.	Water.
	Inches.	Inches.	Inches.	Inches.	Inches	Inches.
ry	2·870	2·734	2·029	0·136	0·841	0·761
ary ..	1·596	1·524	1·085	0·072	0·511	0·603
.. ..	1·936	1·605	0·879	0·334	1·060	1·065
.. ..	1·428	1·117	0·275	0·311	1·153	2·098
.. ..	2·056	1·656	0·105	0·400	1·951	2·753
... ..	2·205	1·572	0·156	0·633	2·049	3·142
.. ..	1·774	1·212	0·013	0·562	1·761	3·443
t	2·332	1·783	0·113	0·549	2·219	2·850
nber ..	2·347	1·737	0·071	0·610	2·276	1·606
r	2·730	2·402	0·515	0·328	2·215	1·056
ıber ..	2·021	1·963	0·833	0·058	1·188	0·707
ıber ..	2·422	2·173	1·508	0·249	0·914	0·574
e Year ..	25·720	21·478	7·582	4·242	18·138	20·658

nass of sand which fills one of the percolators supplies :me example of a soil of the lowest water-holding and y power; the rain passes through it without hindrance, little water is evaporated from the surface even in the f summer. In the whole year the quantity calculated as ted amounts to but 4·242 inches. The true amount of tion is probably, however, greater than this, as it is not common for the drainage from this gauge to exceed the owing, as Mr. Greaves supposes, to condensation of

water directly from the atmosphere. This excess of drainage over rain occurs most frequently in January and February.

On the turfed soil the amount of evaporation from January to March is very similar to that observed on the bare soil at Rothamsted; but from April to September—the growing season of the grass,—practically no drainage takes place, nearly the whole of the rainfall being evaporated. Drainage-water was indeed collected in July and August only on two, in June on three, and in May and September on four occasions during the fourteen years. The average amounts of water evaporated from the turf during summer, winter, and the whole year, namely, 11·409, 6·731, and 18·138 inches, are very similar to those noted at Rothamsted; they are so, however, simply from the very moderate amount of rainfall supplied to the soil. In the wet summer of 1860, 15·608 inches were evaporated by the turf in six months; and in the wet season of 1872, the evaporation during twelve months reached 25·141 inches. There is thus but little constancy in the amount of evaporation, which depends largely on the amount of rainfall, and on the activity of the vegetation. With a heavier rainfall we should doubtless obtain more constant figures.

The figures representing the evaporation from a water surface are full of interest. The average summer evaporation is 15·8[illegible] inches; that for winter, 4·766 inches; the total for the year 20·658 inches. The amount of variation is very considerable. In 1862 the annual evaporation was only 17·332 inches; in the hot season of 1868 it reached 26·933 inches. There are some obvious reasons why the evaporation from a water surface should be more variable than that from a bare soil. On a water surface sunshine and wind must always produce their full effect, while on soil evaporation receives a check as soon as the surface is dried. Another disturbing cause in Mr. Greaves's determinations has been variable condensation from the atmosphere, making the winter evaporations appear lower than they really are.

Mr. Evans's experiments are even more striking examples of the disturbing action of vegetation than those of Mr. Greaves. The average rainfall during fifteen years has been 25·55 inches. Throughout this period the absence of drainage from the turfed soil during the summer months has been even more complete than in Mr. Greaves's experiments. The summer drainage from the turfed soil has averaged 0·35 inch, the evaporation 12·12 inches. The winter drainage has been 5·23 inches, the evaporation 7·85 inches. In the whole drainage-year the average drainage has been 5·58 inches, the evaporation 19·97 inches. The summer evaporation, however, actually ranges f[illegible]

·09 inches, and that of the whole year from 13·20 to 26·55 :hes. This wide range in the amount of evaporation is in rt due to the insufficient supply of rain. The full evaporating wer of the turf has perhaps not yet been shown, the whole of e rainfall having been evaporated even in the wettest summer the fifteen years. In these experiments the distribution of e rain has a marked effect on the amount of drainage. Rain-lls not sufficiently heavy to penetrate the turf are probably aporated, while those passing the turf appear, more or less, as ainage.

In the percolator filled with chalk, the average annual drainage s been 8·79 inches, and the evaporation 16·76 inches. In this se the soil would probably be less compact, and the growth of ass less vigorous, than in the percolator filled with arable soil; e drainage is therefore naturally larger, and the evaporation s.

3. *Composition of the Drainage-Waters.*

Before giving the analyses of the drainage-waters obtained m the drain-gauges at Rothamsted, it will be well to state previous manuring of the soil, and what is known respect- its composition. The soil forming the drain-gauges was eviously to 1870 under ordinary arable cultivation. In 1870 was bare fallow, save that two rows of barley (manured with ano) were sown by mistake along one end of each of the ts afterwards isolated as drain-gauges. In 1869 the crop s wheat unmanured. In 1868 swedes were grown with guano l superphosphate. The few crops immediately preceding swedes were all cereals, grown with artificial manures, erally with guano.

The soil was sampled to the depth of 54 inches, while lying bare fallow in June 1870. The amount of nitrogen found each successive 9 inches of dry soil, stones removed, was as en in Table XXVI. (p. 56).

The surface-soil was apparently rather richer in nitrogen n the ordinary arable soil of the Rothamsted farm, the first aches of which usually contains about 0·135 per cent.

Besides the constituents originally present in the soil we must ar in mind that it annually receives from the atmosphere a tain quantity of matter in rain-water, and also by its own ect absorption. Sulphates and chlorides, with smaller antities of organic matter, ammonia, and nitrates, are thus rularly supplied. As a large portion of the rain-water is aporated after falling on the soil, we should expect to find in drain-water some of the constituents of the rain in increased oportion; and this is actually the case when, as in the present

menced. The drainage-water was collected in successive portions, and analysed with the following results:—

TABLE XXVII.—The AMOUNT and COMPOSITION of the DRAINAGE-WATER obtained in SUCCESSIVE EXTRACTS from an ARABLE SOIL.

Water put on. Grams.	Drainage-Water. Grams.	Composition of Drainage-Water.			
		Chlorine.		Nitrogen as Nitric Acid.	
		Per Million.	Grams.	Per Million.	Grams.
1000	50	1068·5	0·05343	188·3	0·00942
	50	266·0	0·01330	82·7	0·00414
	50	21·3	0·00106	8·0	0·00040
100	100	none	none	1·7	0·00017
1100	250	..	0·06779	..	0·01413

The effect of the rapid percolation of water through a dry soil, free from cracks and fissures, is certainly very remarkable. From the 7 lbs. of soil experimented on more than three-quarters of the diffusible salts are removed in the first 50 cubic centimetres (about 1¾ fluid oz.) of drainage-water, and almost the whole amount of the diffusible salts is obtained in the first 150 cubic centimetres of drainage-water. The column of water passing through the soil thus evidently dissolved the chlorides and nitrates at its lower edge, and kept pushing this solution before it as a narrow layer, which was finally expelled in the first portions of the drainage-water.

To obtain this expulsion of the diffusible salts in so small an amount of drainage-water it is essential that the soil should be dry, and that the percolation of the water should take place rapidly. The experiment just quoted was intentionally aided by the air-pump, and was completed in less than 4 hours. Another experiment will illustrate what may be expected to take place when these conditions are altered.

A column of soil similar to that just described was first exhausted of its own chlorides by the passage of water through it; 0·3843 gram of pure chloride of sodium (equal to 334 lbs. per acre) was then dissolved in a little water, and poured on the surface of the saturated soil; after standing a week, percolation was commenced, 120 cubic centimetres of water being placed each day on the surface, and about the same amount of drainage-water removed below. For the percolation of this amount of

ʀithout the aid of the air-pump, nearly 24 hours were l. The results were as follows:—

ːXVIII.—Results of Percolation after Chloride of Sodium had been applied to the Soil.

Water put on.	Drainage obtained.	Chlorine in Drainage-Water.	
		Per Million.	Grams.
Grams.	Grams.		
120	117·1	none	none
120	119·4	none	none
120	115·1	none	none
120	120·2	43·8	0·00527
120	115·3	202·0	0·02329
120	118·9	476·0	0·05659
120	114·0	621·0	0·07079
120	123·4	425·0	0·05245
120	118·9	158·0	0·01879
120	120·0	39·8	0·00478
120	119·4	7·6	0·00091
1320	1301·7	..	0·23287

ːommon salt applied contained 0·23313 gram of chlorine; ɔe seen that practically the whole of this was recovered rainage-waters.

chief cause of difference between this and the former ent is the far greater activity of diffusion in the present . The chlorides when applied in solution to the wet an to spread downwards, though no drainage was taking nd at the end of a week had made such progress that ys of percolation sufficed to bring chlorides into the ɜ-water. That this early appearance of chlorides was heir previous downward diffusion is proved by the small ion of water at the surface necessary to cause this appear- Had the chlorides remained at the surface it would have l the application of 850 grams of water to cause their ɪn, this being the amount of water necessary to displace er already held by the soil; but in fact the chlorides ɔ appear when only 480 grams of water had been applied. s there only downward diffusion; upward diffusion was ive during the 11 days of percolation; and consequently ɪr of water richest in chlorides was followed by a con-

siderable amount of drainage containing chlorides in gradually diminishing proportion. The nett result of the 18 days' diffusion was that it required 1320 grams of water to expel the chlorides from the soil, whereas the chlorides were expelled by only 1000 grams of water in the previous speedy percolation. The chlorides are now also distributed throughout 950 grams of drainage-water, whereas previously the whole was contained in 150 grams.*

We see from these experiments that the expulsion of the diffusible salts from a soil is effected most readily when the percolation is rapid; that consequently a heavy rainfall, occurring in a few days, is far more dangerous in this respect than the same rainfall spread over a month. We see also that but for the action of diffusion, and other causes tending in the same direction, the soluble salts contained in a soil would descend on the application of rain in a well-defined band, and be suddenly discharged in the drainage-water; whereas in fact the diffusion always going on in a moist soil tends to distribute the chlorides and nitrates equally throughout the mass of soil, and thus produces a considerable uniformity in the composition of the drainage-water. Evidence of the existence of bands of saline solution in the soil will, however, be found when we have, by and bye, to consider the drainage-waters obtained from manured land.

A word must next be said on some percolation experiments in which nitrate of sodium was applied to the soil; these illustrate afresh the facts just pointed out, and at the same time exhibit some special relations of nitrates with soil, which we shall do well to bear in mind. The first experiment was strictly comparative with that made with chloride of sodium just described; the two experiments were indeed conducted side by side, and in precisely the same manner. The quantity of pure nitrate of sodium employed was 0·5588 gram (equal to 519 lbs., or 80 lbs. of nitrogen, per acre), the exact chemical equivalent of the chloride of sodium used in the comparative experiment. The saturated soil was allowed to stand for a week after the application of the nitrate; successive quantities of water were then placed on the surface, and the drainage-water obtained collected and analysed, yielding the results given in Table XXIX.

It was observed in making the third extract that the water had begun to percolate more slowly than in the experiment in

* The tardy expulsion of the chlorides from a wet soil was probably determined in part by other causes besides diffusion, but the view given in the text will suffice for our present purpose.

XXIX.—Results of Percolation after Nitrate of Sodium had been applied to the Soil.

Water put on. Grams.	Drainage obtained. Grams.	Nitrogen as Nitrates and Nitrites in Drainage-Water.	
		Per Million.	Grams.
120	116·4	none	none
120	118·7	none	none
120	97·0	none	none
120	134·0	none	none
120	126·3	9·0	0·00114
120	120·4	57·3	0·00690
120	120·6	72·6	0·00876
120	117·2	20·0	0·00234
120	118·9	0·5	0·00006
1080	1069·5	..	0·01920

ss at the side with chloride of sodium ; this resistance to ssage of water increased, so that by the fifth extract the ıtion of 120 cubic centimetres of water occupied twice the :quired in the experiment with chloride of sodium. The)f this retardation was quite apparent; large transverse filled with gas, had formed in the soil, the largest being three inches below the surface ; no such cracks appeared chloride of sodium percolator.

:urning to the analyses of the drainage-water, we see that s did not begin to appear until the fifth extract, that they l their maximum in the seventh extract, and were all d at the ninth. The nitrates thus appeared later than orides, and ceased sooner ; the nitrates were spread over :racts, while the chlorides occupied eight. Nitrites were in the drainage-water.

whole of these facts find their explanation when we : the quantity of nitrate recovered in the drainage. The of sodium employed contained 0·09198 gram of nitrogen ; only 0·01920 gram, or 20·9 per cent., was recovered in the ;e-water. It will be recollected that in the corresponding nent with chloride of sodium practically the whole of the e was recovered. How has this serious loss of nitric acid d ? Clearly by reduction of the nitrates in a water-logged stitute of free oxygen. This reduction in question has fected by the organic matter of the soil, and has resulted formation of carbonic acid gas. A part of the nitric acid bably been reduced to ammonia, while a considerable part nitrogen has most likely taken the form of nitrogen gas.)il employed was by no means rich in organic matter,

but the perfect consolidation of the soil, the removal of air by the pump when water was first poured on, and the fact that the soil was always afterwards covered with water, afforded opportunity for the consumption of all available oxygen, and then for the reduction of the nitrates present. The experiment was conducted in April; the temperature was therefore not high.

To confirm these results, the soil already treated with chloride of sodium was made use of for a second experiment with nitrates. The quantity of nitrate of sodium used was double that previously employed. Instead of waiting a week after the application of the nitrate, percolation was started a few hours after its addition to the soil; less opportunity for reduction was thus afforded. The results are as follow:

TABLE XXX.—RESULTS of PERCOLATION after a DOUBLE QUANTITY of NITRATE of SODIUM had been applied to the SOIL.

Water put on. Grams.	Drainage obtained. Grams.	Nitrogen as Nitrates and Nitrites in Drainage-Water.	
		Per Million.	Grams.
120	118·3	none	none
120	117·2	none	none
120	112·2	none	none
120	126·0	none	none
120	126·7	7·6	0·00096
120	119·9	119·3	0·01430
120	119·9	288·3	0·03457
120	119·5	294·8	0·03523
120	120·7	136·2	0·01644
120	122·4	11·9	0·00146
120	115·1	0·8	0·00009
1320	1317·9	..	0·10305

The development of cracks in the soil, the retardation of drainage, and the production of nitrites were observed as before. The nitrate of sodium employed had contained 0·18396 gram of nitrogen; of this 0·10305 gram, or 56 per cent., was recovered in the drainage-water. The absolute loss was really, however, rather larger than in the previous experiment with half the quantity of nitrate; the loss then was 0·07178 gram, while now it amounted to 0·08091 gram of nitrogen.

The reduction of the nitrates in soil to ammonia and gaseous nitrogen, when oxygen has been excluded, has been observed by Schloesing * and others; the fact is of considerable agricultural

* *Comptes Rendus*, lxxvii. 353.

rtance, as showing the loss of nitrates, and even of soil gen, which may occur in ill-drained soils in wet weather.
e will now turn to the composition of the drainage-waters ned from the soils of the three drain-gauges. The first s of analyses was made by Dr. Frankland; the analyses oublished in the 'Sixth Report of the Rivers' Pollution mission, 1874,' p. 62. The results appear in Table XXXI.
r. Frankland's analyses relate to samples of drainage-water cted from all three gauges on five different occasions; on occasion, except the last, drainage was taking place pretty y when the collection was made.
ie first collection (Nov. 20–23, 1870) was made about two ths after the gauges were completed. The summer had a very dry one. No considerable drainage had taken before the collection of the samples; this was especially in the case of the 40 and 60-inch gauges. The waters ysed were clear.
ie second collection, December 15–17, 1870, was about a h after the first; in the interval between the two collections oderate amount of drainage had occurred. The waters ysed were all turbid.
ie third collection, Oct. 30–31, 1872, occurred about two after the first. The preceding summer had been very dry, between two and three inches of drainage had occurred in ber before the collection of the samples. The waters were tly turbid.
ie fourth collection, February 25–26, 1873, was made under different circumstances. The preceding four months had is case been very wet, about 12 inches of drain-water having through the 20-inch gauge. The waters collected arose the melting of snow; all were turbid.
ie fifth collection, April 2–30, 1874, was a mixture of all the ings during one month. Drainage was pretty continuous ghout the month, though at a very gentle rate, barely one- of an inch having been collected from the 20-inch gauge. preceding winter had been dry. The water from the 20-inch e was slightly turbid; the others were clear.
ie first three collections are thus autumn drainage-waters, preceding summers having been dry. Nitrification had tless been active in the upper layer of the soils during the ner months; but as very little drainage had occurred the tes produced had not been to any considerable extent re- d by rain. These drainage-waters were consequently all concentrated character, and particularly rich in nitrates.
ie fourth collection, on the other hand, was made towards lose of a remarkably wet winter, when the soil had been

TABLE XXXI.—ANALYSES by DR. FRANKLAND of DRAINAGE-WATERS from the three DRAIN-GAUGES, 20, 40, and 60 Inches deep, in parts PER MILLION.

Date of Collection.	Total Solid Matter.	Carbon in Organic Matter	Nitrogen as				Chlorine.	Total Hardness.
			Organic Matter	Ammonia.	Nitrates and Nitrites.	Total Nitrogen.		
			SOIL 20 INCHES DEEP.					
Nov. 20–23, 1870	632·8	1·08	0·45	0·00	49·36	49·81	21·5	129
Dec 15–17, 1870	400·4	1·84	0 64	0·00	31·76	32·40	38·0	146
Oct. 30–31, 1872	302·4	1·14	0·45	0·01	26·36	26·82	6·0	166
Feb. 25–26, 1873	160·0	1·42	0·45	0·02	6·07	6·54	9·5	120
April 2–30, 1874	274·4	1·74	0 75	0·20	21·46	22·41	9·5	137
Mean	358·0	1·44	0·55	0·05	27 00	27·60	16·9	140
			SOIL 40 INCHES DEEP.					
Nov. 20–23, 1870	362·4	1·47	0·49	0 00	23·45	23·94	28·6	134
Dec. 15–17, 1870	386 0	2·35	0·82	0·00	23·89	24·71	30·0	131
Oct. 30–31, 1872	273·2	0·96	0·32	0·00	21 06	21·38	8·0	166
Feb. 25–26, 1873	192 4	1·27	0·26	0·01	7·89	8·16	9·5	97
April 2–30, 1874	230·8	1·17	0·54	0·10	16·02	16·66	9·5	120
Mean	289·0	1·44	0·49	0·02	18·46	18·97	17·1	130
			SOIL 60 INCHES DEEP.					
Nov. 20–23, 1870	302·4	1·27	0·42	0·00	28·53	28·95	26·0	153
Dec. 15–17, 1870	366·8	3 71	1·16	0·21	24·89	26 26	21·5	85
Oct. 30–31, 1872	326·8	0·98	0·37	0 01	23·65	24 03	10·5	126
Feb. 25–26, 1873	223 6	1·68	0·40	0·02	7 50	8 01	9·5	104
April 2–30, 1874	264 0	0 98	0 42	0 16	17 32	17 90	9·5	130
Mean	314·7	1·72	0 55	0 08	20 40	21 0[illegible]	15·4	110

l by the percolation of a large amount of water. The ge-water now was less concentrated than before, and was ılly poor in nitrates.

: fifth collection was in spring, at the end of a dry winter. ıte of drainage having been very slow, the water doubtless ented the general discharge of the soil, and owed but little :ct channel drainage. The water is seen to be much more ıtrated than that obtained at the fourth collection, but does ual in this respect the three autumn drainage-waters.

king at the analyses generally, we see that ammonia is absent, or occurs in very small quantity. The amount of c matter dissolved in the water is but small; it is increased the water is turbid; it is in all cases highly nitrogenous. ıean ratio of organic nitrogen to carbon in the drainage- from the three gauges is 1 : 2·6, 1 : 2·9, and 1 : 3·1, the tion of carbon apparently increasing with the depth of the This, however, can hardly be established as a fact from w analyses now before us. The proportion of carbon ıest in the turbid waters; the mean ratio of nitrogen to in the six turbid waters being 1 : 3·3, and in the nine r slightly turbid waters 1 : 2·6. Turbidity in a drainage s a sign that direct channel drainage has occurred, matter brought immediately from the surface.

E. J. Mills has already called attention ('Trans. Chem. 1878, p. 64) to the constancy of the relation between the :n and carbon of the organic matter found in clear well- ·ainage-waters. He considers that the slow oxidation organic matter undergoes in a soil finally reduces all ɔf organic matter to a few simple compounds, in which bon and nitrogen have the relation $C_{12} : N_3$, $C_{12} : N_4$, or C_{12} : ı the drainage-waters we are now considering the com- n of the organic matter corresponds with the second of ɔve ratios. The gradual increase in the proportion of ·n contained in the organic matter as oxidation in the soil ls, is strikingly shown by the determinations of carbon rogen which have been made in the Rothamsted soils. In face soil (first 9 inches) of pasture land, with roots as far ıible removed, the proportion of nitrogen to carbon is . : 13. In the clay subsoil of the same land (fifth and ' inches) the proportion is about 1 : 6. In the soluble : matter contained in drainage-water we have just seen that ›portion reaches 1 : 2·6. Respecting the nature of these ıous organic bodies, and the part they possibly play in utrition, very little is at present known.

chlorides found in the first two analyses greatly exceed unt any quantity subsequently found; this large propor-

tion of chlorides was probably due to the previous manuring with guano. The amount of lime present in the waters was considerable, as shown by the "hardness." In the later analyses the total solid matter is chiefly made up of calcium salts—nitrate, sulphate, and carbonate; alkali salts must also, however, have been present in considerable quantity. In the earlier samples, the alkali salts form the largest ingredient; at least the calcium salts can account for only a small part of the solid matter.

If we compare together the drainage-waters from the three gauges, we see that as far as the total solid matter and nitrates are concerned, the drainage from the 40-inch gauge is weaker than from either of the others, the order of strength is in fact 20, 60, 40. This comparatively low proportion of nitrates in the drainage from the 40-inch gauge is shown in the first analysis made in 1870, and is equally shown in nearly all the analyses that have been made since; the cause must apparently be sought in some original difference in the soil forming this gauge.

We pass now to the more recent analyses of these drainage-waters. Since September, 1874, a sample has been taken from the drainage of each day, and mixed monthly samples prepared representing the drainage from each gauge. It being uncertain whether the samples could be analysed, the sampling was at first roughly done; but since May, 1877, a fixed fraction of each day's running has been carefully taken, so that the mixed monthly sample might exactly represent the whole drainage. The earlier samples were not examined till the spring of 1877, owing to the lack of analytical assistance in the Laboratory. At that time many of the samples were found to be ill preserved, and had to be discarded; determinations of nitric acid were then made in the remainder. Since May, 1877, determinations of nitric acid and of chlorine have been made as soon as possible after the completion of the monthly sample. It is obvious that the analyses of the earlier samples do not possess the same quantitative value as those more recently done; we shall give, however, in a separate table (XXXII.) the amounts of nitrogen as nitric acid found in the best preserved samples in the earlier series, as they serve to illustrate some facts connected with these drainage-waters. The nitric acid has in all cases been determined by the improved indigo method ('Trans. Chem. Soc.,' 1879, p. 578), and the chlorine by the volumetric method already noticed.

The drain-gauges did not run during June and July 1876, and to a scarcely appreciable extent in May of the same year.

Two facts are pretty clearly shown by these somewhat disconnected determinations. 1. That the maximum richness in

LE XXXII.—NITROGEN as NITRIC ACID in some MIXED [ONTHLY SAMPLES of DRAINAGE-WATER from the three DRAIN-AUGES, 1874–77.

MONTHS.	Drainage in Inches.			Nitrogen as Nitric Acid per Million of Water.		
	20-Inch Gauge.	40 Inch Gauge.	60-Inch Gauge.	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.
1874.						
ember	0·634	0·249	0·212	25·5	20·0	15·1
ber	1·525	1·258	1·024	39·6	30·5	22·5
ember	1·209	1·045	0·687	..	..	20·0
ember	1·155	1·340	1·039	..	..	23·2
1875.						
.. ..	0·349	0·262	0·140	25·1	23·5	22·5
.. ..	3·292	3·661	3·346	26·1	21·6	22·8
ust	0·001	0·025	0·030	..	20·9	23·8
ember	0·890	0·829	0·707	38·3	26·7	25·9
1876.						
h	1·283	1·745	1·585	9·3	10·9	14·6
l	1·360	1·664	1·720	..	11·5	12·2
ust	0·146	0·141	0·025	22·0	18·7	..
ember	2·296	2·236	2·011	25·2	..	19·8
ember	5·212	5·741	5·252	9·8	10·0	11·5
1877.						
ary—April ..	7·003	8·467	7·930	8·1	9·1	12·0

ates occurs in the early autumn drainage, the proportion inishing through the winter, and reaching a minimum in ing. 2. That in early autumn the drainage from the 20-inch ge is richest in nitrates, but that in late winter and spring drainage from the 60-inch gauge becomes generally the est. These two facts will be found further illustrated by the re recent analyses recorded in Table XXXIV. (p. 72); they nit of ready explanation. The summer, as already mentioned, he season when nitrates are most abundantly produced in the face soil; but little drainage occurs in summer time, owing the high rate of evaporation; the nitrates therefore accumu-e in the soil. In the autumn drainage becomes active, and the shing-out of the nitrates commences; the first drainage is not, wever, always the strongest, as the nitrates are most abundant the surface, and must be displaced by rain, and allowed time diffusion before they can appear in quantity in the drainage-ter. The drainage from the shallowest soil is the first to ow a maximum contents of nitrates, because the amount of

displacement and diffusion required to bring the nitrates within the area of discharge is here the smallest; for the very same reason the shallowest soil is also the most quickly washed out, while the deepest soil, having a larger mass available for the diffusion of the nitrates, parts with them more equably.

Before considering the more complete series of monthly analyses, extending from May, 1877, to the present time, it will be convenient to give the results obtained in March and April, 1879 (Table XXXIII.), when a detailed examination was made

TABLE XXXIII.—NITROGEN as NITRATES in DRAINAGE-WATERS, from the 60-INCH DRAIN-GAUGE in MARCH and APRIL, 1879.

Date.	Rain. Inches.	Drainage. Inches.	Nitrogen as Nitrates per Million.	Date.	Rain. Inches.	Drainage. Inches.	Nitrogen as Nitrates per Million.
March 1	..	0·091	14·2	April 1	..	0·013	15·8
,, 2	0·016			,, 2	0·009	0·009	15·5
,, 3	0·056	0·017	14·6	,, 3	0·180	0 010	10 8
,, 4	0·015	0·015	14 4	,, 4	0·008	0·008	14 9
,, 5	0·038	0·014	13·2	,, 5	0·060	[illegible]	8·1
,, 6	0·004	0·015	14·8	,, 6	0·592		
,, 7	0·005			,, 7	0·094	0·153	11·3
,, 8	0·008	0·014	15·3	,, 8	..	0·045	13·7
,, 9	0 005			,, 9	0·204	0·021	12 5
,, 10	0·133	0·014	14·9	,, 10	0·054	0·036	13 9
,, 11	..			,, 11	0·008	0·018	15 4
,, 12	..	0·011	15·0	,, 12	0·138	0·282	10·3
,, 13	0·008			,, 13	0·418		
,, 14	0·153	0·011	13·9	,, 14	0·192	0·067	12 2
,, 15	0·005			,, 15	0·204	0 114	12·3
,, 16	0·006	0·009	14·7	,, 16	..	0 103	12 3
,, 17	..			,, 17	0·100	0 027	14 0
,, 18	0·090	0·011	15·0	,, 18	0·005	0·013	14·6
,, 19	..			,, 19	0·156	0 024	7·3
,, 20	..			,, 20	0·152	0·045	9 6
,, 21	0·039	0·007	15·9	,, 21	0·004	0·028	14 8
,, 22	..			,, 22	0·027	0·017	14·6
,, 23	..			,, 23	0·156	0·029	7 0
,, 24	0·156	0·004	16·6	,, 24	0·005	0·014	14 0
,, 25				,, 25	0·111	0·016	13·4
,, 26				,, 26	0·012	0·015	14·6
,, 27	..	0·007	16·4	,, 27	0·020	0·012	14 6
,, 28	0·080			,, 28	0·002	0 007	15 0
,, 29	0·083			,, 29	0·010	0·006	15·1
,, 30	0·250	0·017	11·9	,, 30	0·025	0 006	15 3
,, 31	0·094			..	..	..	.
Whole Month	1·184	0·257	14 2	Whole Month	2·791	1·376	11 2

of the runnings from the 60-inch gauge, as these results will help to interpret the remainder.

The winter of 1878–9 had been extremely wet, and the drain- : collected up to the middle of February far exceeded the rmal quantity. March, however, was dry, so that the drain- iges almost ceased running, and it was necessary in the sent case to allow the drainage-water to accumulate for two or ee days in order to obtain sufficient for analysis. The rain dited to March 24–26 was really snow, which, having thawed, s measured on the last of these days. The snow on the soil of drain-gauge would melt later. In April the amounts of rain l drainage were much more considerable.

The analyses of the drainage-waters during March display a siderable amount of uniformity. The more considerable ns, namely, those of the 10th, 14th, 26th, and 30th, do not, ept in the last instance, appreciably increase the amount of inage, but they have all a more or less distinct effect in porarily diminishing the proportion of nitrates in the inage-water.

The results obtained in April, with greater rainfalls, are much e striking. Here, as before, small rainfalls, as those of the , 9th, 19th, 20th, 23rd, and 25th, have a very slight effect on amount of drainage, but each of them temporarily diminishes nitrates in the drainage-water, in some cases to less than their usual quantity. Larger rains, as those of the 6th and ı, increase the quantity of drainage as well as diminish the portion of nitrates.

. study of these results plainly shows that the dry weather wet weather drainages from the soil were quite distinct in position. In dry weather a small discharge took place from lowest layer of the 5 ft. of soil, which alone remained rated; this drainage-water contained pretty uniformly ng the period of the experiment about 15 parts of nitrogen million in the form of nitrates. When a small rainfall irred the quantity of the discharge was scarcely increased, it became considerably diluted, the drainage from the est layer of soil being now mixed with rain-water, which come through open channels directly from the surface. h a heavier rain, pressure was brought to bear on the water mn in the soil, and the discharge from the lowest layer then much increased, but diluted as before with direct nnel water.

nother instance of the same character may be quoted. The nage from the 20-inch and 60-inch gauges was collected ı on the morning and evening of January 14th, 1879; ween the two collections a thaw of snow had taken place. : nitrogen existing as nitric acid per million of water was as ows:—

	20-Inch Gauge.	60-Inch Gauge.
Morning Collection ..	6·4	12·7
Evening Collection ..	5·7	6·3

We have, therefore, to bear in mind that the strongest drainage-waters are those obtained after rain has ceased; and that the composition of the drainage-water may be considerably influenced by the varying amount and distribution of the rain; the rain applied to the surface of a soil not simply displacing the water below, but in part proceeding directly to the area of discharge through the open channels of the soil.

The results of the analyses of the mixed monthly samples of drainage-water since May 1877 will be found in Table XXXIV. (p. 72). The amounts of monthly drainage there given will be found in a few cases not to correspond with those found in Table XIX. (p. 34). Thus the amounts credited to the 40-and 60-inch gauges in April 1878, and to the 20-inch gauge in February 1879, are in excess of the numbers previously given. The quantities now stated are the actual amounts of drainage passing through the soil; but, as already explained (p. 32), they are known to be excessive in these particular cases from accidental circumstances, and were therefore corrected in the earlier table. Such corrections are here, however, inadmissible, as our object is to ascertain the total quantity of nitric acid extracted from the soil. In the case of August 1879, the quantity of drainage-water sampled for analysis from all the gauges was less, and in the case of the 60-inch gauge much less, than that quoted in the table; owing to the loss of part or all the water belonging to the storm of August 2–3. The determinations of nitrates and chlorides for this month are consequently somewhat above the truth, the water analysed being stronger than the whole drainage of the month; the error will be least with the 20-inch, and most with the 60-inch gauge.

In January 1880, we were disagreeably surprised by finding a large worm come through the tap of the measuring cylinder of the 20-inch gauge. On testing the drainage-waters for ammonia a considerable quantity was found in the water from this gauge, and a small quantity in that from the 60-inch gauge, but none in that from the 40-inch gauge. The fronts protecting the funnels were then taken down. A number of dead worms were found on the funnel of the 20-inch gauge, and many worm casts dropped from the perforations in the roof. On the funnel of the 60-inch gauge two worms were found. The for[illegible]

s clean. The whole of the funnels and collectors were roughly cleaned. Since this time a careful examination of funnels has been made on the first day of each month. In enteen months one or more small worms have four times en found on the funnel of the 20-inch gauge, and worm casts seven occasions. On the funnel of the 40-inch gauge a worm s found twice, and a slug three times. The funnel of the -inch gauge has remained uniformly clean. The ammonia the waters disappeared immediately after the cleansing of the nels in January.

The fact that the drainage-water from two of the gauges was one time plainly contaminated with decaying animal matter turally suggests a doubt as to the nitric acid determinations these waters. Has the nitric acid found been due to any nsiderable extent to the nitrification of this animal matter?— d are the quantities of nitric acid consequently higher than ose of normal drainage-water? We believe that the consider- le invasion of worms during the early winter of 1879–80 was special occurrence, the severity of the frost causing the worms descend further than usual in the soil. The drainage-waters ve frequently been tested for ammonia (by direct application the Nessler test) both before and after this occurrence, but ays with negative results. Again, during the last seventeen nths, in which the funnels and collectors have been kept as n as possible, the amounts of nitric acid found have not wn any diminution; indeed, during September 1880 a larger ntity of nitric acid was obtained in the drainage than in any eding month as yet recorded. While, therefore, it seems pos- e that the nitric acid found in the drainage-water of the inch gauge may have been rather abnormally high during the ter of 1879-80, we are not disposed to think that the eral bearing of the results has been disturbed by the occa- al presence of worms. It must also be recollected that al life is present in all soils, indeed, often to a far greater nt than is usually imagined, and that the nitrification of the onia resulting from decaying animal matter is therefore not abnormal occurrence, but one of the ordinary sources of the ic acid in drainage-water.

Ve have just stated that ammonia is not a usual constituent the drainage-water from the gauges. The waters have also n from time to time examined for nitrous acid, but nothing ond a minute trace has ever been found. The process of ification in the soil is clearly very complete.

Turning now to the determinations recorded in Table XXIV. (p. 72) we shall at once remark the much lower ount of nitric acid contained in the drainage from the 40-inch

Table XXXIV.—Amount of Nitrogen as Nitrates, and of Chlorine,

	Amount of Drainage.			Nitrogen as Nitrates per Million of Water.		
	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.
1877.	Inches.	Inches.	Inches.			
May	0·445	0·548	0·510	11·5	10·3	15·1
June	0·026	0·096	0·102	8·1	8·2	14·1
July	0·560	0·514	0·440	20·3	15·0	19·1
August	0·384	0·387	0·313	29·6	17·5	21·7
September	0·205	0·254	0·207	25·4	15·5	21·0
October	0·540	0·505	0·349	30·9	18·6	23·4
November	4·031	4·201	3·824	12·5	11·5	13·7
December	1·742	1·982	1·752	13·4	10·9	14·3
Total 8 Months ..	7·973	8·487	7·537	15·4	12·3	14·9
1878.						
January	1·101	1·382	1·200	13·0	11·1	15·4
February	1·013	1·203	1·132	10·5	8·9	11·7
March	0·273	0·503	0·458	13·2	9·5	14·0
April	2·349	2·822	3·467	6·6	6·3	7·6
May	1·479	1·846	1·502	13·3	9·5	14·0
June	0·611	0·856	0·765	13·3	9·9	13·0
July	0·009	0·032	0·063	11·5	10·7	13·3
August	1·331	1·169	1·129	23·0	13·6	16·9
September	0·076	0·122	0·113	17·9	11·2	16·2
October	1·370	1·391	1·103	18·6	14·0	16·4
November	3·771	4·067	3·665	11·1	9·7	11·9
December	1·108	1·374	1·543	12·0	8·3	11·4
Total 12 Months ..	14·490	16·749	16·150	12·8	9·6	12·1
1879.						
January	2·470	2·652	2·412	11·5	7·7	11·3
February	5·734	4·436	4·213	7·2	6·0	9·1
March	0·138	0·384	0·257	15·2	7·7	14·1
April	1·270	1·508	1·376	12·2	7·4	11·1
May	1·217	1·393	1·297	9·5	6·3	9·9
June	2·158	2·239	2·186	8·3	6·8	9·3
July	1·829	1·965	1·806	11·0	7·9	11·4
August	4·601	4·598	4·346	9·3	7·0	11·4
September	1·110	0·999	0·920	2·6	9·2	13·3
October	0·221	0·422	0·426	12·7	9·3	13·3
November	0·195	0·116	0·099	16·2	9·0	15·6
December	0·413	0·490	0·442	16·5	8·3	13·1
Total 12 Months ..	21·353	21·103	19·843	9·7	7·2	10·9
1880.						
January	0·482	0·611	0·457	16·4	9·7	14·2
February	2·360	2·591	2·301	17·7	11·3	13·9
March	0·038	0·095	0·065	15·4	8·0	12·6
April	0·493	0·533	0·434	16·7	10·5	14·2
May	0·002	0·021	0·028			
June	0·010	0·006	0·020	21·9	12·7	16·0
July	1·352	1·229	1·062			
August	0·214	0·279	0·231	21·6	11·2	15·0
September	3·964	3·931	3·779	17·9	13·1	15·6
October	4·466	4·448	4·070	12·6	9·2	10·0
November	2·244	2·387	2·141	10·4	7·8	10·9
December	2·614	2·652	2·661	7·1	6·9	9·4
Total 12 Months ..	18·439	18·955	17·279	14·3	10·1	11·6
1881.						
January	1·013	1·121	1·321	5·0	4·5	6·6
February	3·426	3·707	3·287	4·8	4·9	7·6
March	1·663	1·779	1·654	3·9	4·6	8·6
April	0·003	0·010	0·030	..	6·3	12·1
Total 4 Months ..	6·105	6·617	6·292	4·3	4·7	7·6
Total 48 Months ..	68·360	71·941	67·080	11·8	8·6	11·6
Average 12 Months	17·090	17·985	16·770	11·8	8·6	11·6

in the MONTHLY DRAINAGE-WATERS from the THREE DRAIN-GAUGES.

Nitrogen as Nitrates per Acre.			Chlorine per Million of Water.			Chlorine per Acre.		
20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.	20-Inch Gauge.	40-Inch Gauge.	60-Inch Gauge.
lbs.	lbs.	lbs.				lbs.	lbs.	lbs.
1·16	1·28	1·75	12·7	4·7	5·0	1·28	0·58	0·58
0·05	0·18	0·33	..	4·0	5·7	..	0·09	0·13
2·57	1·74	1·95	5·9	5·7	5·3	0·75	0·66	0·53
2·56	1·53	1·54	7·3	6·3	6·3	0·63	0·55	0·45
1·18	0·89	0·98	6·6	6·0	6·0	0·31	0·34	0·28
4·06	2·13	2·06	10·0	8·1	9·0	1·31	0·93	0·79
11·40	10·93	10·90	5·0	5·6	5·3	4·56	5·32	4·59
4·89	4·89	5·67	5·3	5·2	4·5	2·09	2·33	1·78
27·87	23·57	25·27	6·1	5·6	5·4	10·93	10·80	9·13
3·24	3·42	4·18	5·0	5·0	5·0	1·25	1·54	1·36
2·41	2·42	3·00	4·0	4·1	4·0	0·92	1·12	1·02
0·82	1·08	1·54	4·7	4·4	4·6	0·29	0·50	0·48
3·51	4·02	5·96	3·1	3·3	3·0	1·65	2·11	2·35
4·45	4·10	4·76	3·7	3·7	3·6	1·24	1·55	1·22
1·84	1·92	2·36	4·0	4·5	4·0	0·55	0·87	0·68
0·02	0·08	0·19	4·0	5·4	3·9	0·01	0·04	0·06
6·93	3·65	4·32	4·5	4·9	4·7	1·36	1·30	1·20
0·30	0·31	0·42	4·6	4·8	4·8	0·08	0·13	0·12
5·77	4·41	4·14	4·9	5·1	5·3	1·52	1·61	1·32
9·47	8·93	9·54	3·8	4·3	4·1	3·24	3·96	3·40
3·01	2·58	4·12	4·1	4·1	3·8	1·03	1·27	1·33
41·77	36·92	44·53	4·0	4·2	4·0	13·14	16·00	14·54
6·59	4·62	6·26	2·8	3·7	3·3	1·56	2·22	1·85
9·34	6·93	8·78	4·5	3·6	3·4	5·84	3·61	3·24
0·47	0·49	0·82	3·6	3·7	4·0	0·11	0·24	0·23
3·51	2·53	3·48	3·9	3·9	3·7	1·12	1·33	1·15
2·62	1·99	2·91	4·2	3·6	3·8	1·16	1·13	1·12
4·05	2·94	4·60	2·9	3·1	3·0	1·41	1·57	1·48
4·55	3·51	4·66	3·4	3·8	3·6	1·41	1·69	1·47
9·68	7·28	11·21	1·3	2·2	2·7	1·35	2·29	2·66
3·21	2·08	2·77	2·2	2·8	3·4	0·55	0·63	0·71
0·64	0·89	1·27	2·7	3·0	3·3	0·14	0·29	0·32
0·71	0·24	0·30	3·7	4·2	4·1	0·16	0·11	0·09
1·54	0·92	1·21	4·8	4·2	3·2	0·45	0·47	0·32
46·91	34·42	48·27	3·2	3·3	3·3	15·26	15·58	14·64
1·68	1·34	1·47	3·0	3·6	3·9	0·33	0·50	0·40
9·45	6·62	6·73	4·0	4·0	4·0	2·14	2·34	2·08
0·13	0·19	0·25	4·5	3·8	5·0	0·04	0·07	0·10
1·86	1·27	1·39	3·9	3·9	3·9	0·44	0·47	0·38
6·76	3·61	4·02	4·9	4·3	4·5	1·51	1·22	1·13
1·05	0·71	0·79	4·8	4·3	3·8	0·23	0·27	0·19
15·96	11·65	10·69	3·0	3·6	2·9	2·69	3·20	2·48
12·93	9·26	9·95	3·3	3·1	3·2	3·33	3·12	2·95
5·28	4·21	5·28	3·9	3·8	4·0	1·98	2·05	1·94
4·52	4·45	5·70	3·4	3·6	3·5	2·16	2·30	2·12
59·62	43·31	46·26	3·6	3·6	3·5	14·85	15·54	13·77
0·69	1·14	1·97	4·8	4·2	4·2	1·10	1·07	1·26
3·72	4·11	5·50	3·8	4·2	4·0	2·95	3·52	2·97
1·47	1·81	2·47	3·9	3·9	3·7	1·47	1·57	1·38
..	0·01	0·08	..	3·0	3·7	..	0·01	0·03
5·88	7·07	10·02	4·0	4·1	4·0	5·52	6·17	5·64
182·05	145·29	174·35	3·9	3·9	3·8	59·70	64·09	57·72
45·51	36·32	43·59	3·9	3·9	3·8	14·93	16·02	14·43

gauge, as compared with that found in the drainage from the other gauges. Taking the average composition of the whole of the drainage from the three gauges during four years, we have for the 20-inch gauge, 11·8; for the 40-inch gauge, 8·9; and for the 60-inch gauge, 11·5 parts of nitrogen as nitrates per million of water. This considerable deficiency of nitrates in the drainage from the 40-inch gauge is apparent in Frankland's earliest analyses of these drainage-waters; it is probably, therefore, due to some original difference in the composition of the soils. No such difference is perceived in the proportion of chlorides contained in the three drainage-waters, which average 3·9, 3·9, and 3·8 parts of chlorine per million.

There is not much regularity of sequence visible in the proportion of nitrates and chlorides found from month to month in the drainage-waters, and still less in the weights of nitrogen and chlorine removed monthly from the soil in this manner. The conditions suitable for nitrification—the temperature and humidity of the soil—have varied extremely; the monthly amounts of drainage have varied quite as much. Both the production and removal of nitrates have thus proceeded very irregularly. A reference to Table XV. will show that the supply of chlorides in the rain has been equally irregular. The series is too short for these irregularities to disappear by taking an average of the monthly results; we must, therefore, confine our attention to a few principal points.

The two facts we have already pointed out in the earlier results find here fresh illustration; thus the drainage-waters are seen to be generally richest in nitrates from July to October, and poorest from April to June. The extremely wet and cold summer of 1879 forms an exception; the waters did not here show a high proportion of nitrates at the usual period of maximum; while in the dry autumn and winter which followed the proportion of nitrates is for the season unusually high.

We have evidence again of the greater relative richness of the drainage from the 20-inch gauge during the season of maximum proportion of nitrates, and its relative poverty, as compared with the water from the deepest gauge, as the season of minimum nitrates approaches. This gradual change of relation between the waters of the 20-inch and 60-inch gauges is most conspicuously seen in the autumn and winter of 1877–78, and of 1880–81. It follows from what has just been stated that the range in composition is greatest in the water from the 20-inch gauge, less in that from the 40-inch gauge, and least in that from the 60-inch gauge. At a still greater depth the drainage-water would probably have a uniform composition all the year round.

The quantity of nitrates removed in the autumn drainage-raters is generally greater than at any other period of the year, he drainage-waters being most concentrated at this season, and he drainage also usually abundant. This excess during autumn s most marked in the drainage from the shallowest soil. Thus rith the 20-inch gauge the nitrates removed during the last six nonths of the year have been on an average 65·3 per cent. of the nnual quantity; with the 40-inch gauge, 62·6 per cent.; and rith the 60-inch gauge, 59·5 per cent. The amount of drainage or the same period being respectively 56·4, 55·2, and 54·5 er cent.

The effect of a heavy and continuous rain in removing xceptionally large quantities of nitrates from the soil is strik-ngly shown by the results obtained in September 1880. In his month 5·110 inches of rain fell at Rothamsted in five days, nd the quantity of nitrogen as nitrates in the drainage-water rom the 20-inch gauge amounted to nearly 16 lbs. per acre, an mount far larger than that obtained in any other month during he four years. This is quite in accordance with what has been lready said (page 60). A heavy rain, falling in a short time, hould be especially effective in discharging the soluble salts rom a soil, as the smallest opportunity is then afforded for the etention of the salts through upward diffusion within the wet oil.

The proportion of chlorides in the drainage-waters shows far ess range of variation than that of nitrates. The chlorides resent in these soils being derived from the rain are not, like he nitrates, produced chiefly at one season of the year, but are upplied whenever a shower falls. Small rainfalls, we have lready seen, are richer in chlorides than large rainfalls, and he rain of winter is richer than that of summer. The winter rainage contains a larger proportion of chlorides than the ummer drainage; and a maximum proportion of chlorides is ometimes reached towards the end of winter. The maximum, owever, generally occurs towards the end of summer, or the eginning of autumn, the great evaporation of rain from the oil during summer storing up chlorides in a more than usually oncentrated form. In a cold and wet summer, like that of 879, this period of maximum is not perceptible.

If we look at the quantities of chlorine removed by the drain-ge-waters per acre of soil, we shall find a pretty close agree-nent with the quantities of chlorine already given as con-ained in the rain for the same period (Table XV., p. 25). In orty-three months the amount of chlorine supplied by the rain mounted to 47·60 lbs. per acre, or really to somewhat more, as he method of analysis employed gave rather low results. The

quantities of chlorine removed in the drainage-waters during the same time were respectively 52·90 lbs., 57·34 lbs., and 51·50 lbs. for the three gauges. There can, therefore, be little doubt that the soil has been completely washed out, and is now dependent on the rain for all the chlorides it contains.

The quantity of nitrogen as nitrates, and of chlorine removed by the drainage-water from an acre of soil during each of the three drainage years included in the period of the experiment, will be found in Table XXXV.; the results are arranged in the order of the amount of drainage.

TABLE XXXV.—AMOUNTS of NITROGEN as NITRATES, and CHLORINE as CHLORIDES, contained in the DRAINAGE-WATER from the three DRAIN-GAUGES in THREE DRAINAGE YEARS (Oct. to Sept.)

20-Inch Drain-Gauge.				40-Inch Drain-Gauge.				60-Inch Drain-Gauge.			
Year.	Drainage Inches.	Nitrogen lbs. per Acre.	Chlorine lbs. per Acre.	Year.	Drainage Inches.	Nitrogen lbs. per Acre.	Chlorine lbs. per Acre.	Year.	Drainage Inches.	Nitrogen lbs. per Acre.	Chlorine lbs. per Acre.
1879–80	9·743	39·78	8·13	1879–80	10·326	27·44	8·94	1879–80	9·354	28·11	7·49
1877–8	14·591	43·87	15·31	1877–8	16·605	38·95	17·74	1877–8	15·734	45·45	15·65
1878–9	26·772	62·27	20·30	1878–9	26·907	48·29	21·55	1878–9	25·186	63·29	19·96
Mean	17·035	48·64	14·58	Mean	17·946	38·23	16·08	Mean	16·774	45·62	14·36

These three years fortunately include some very different seasons. In 1879–80 we have a year in which the drainage is rather below the normal quantity, and in 1878–9 we have a year in which the drainage is considerably more than twice the normal quantity. We see that an increase in the amount of drainage is accompanied by an increase in the amount of nitrates removed from the soil, but the latter does not increase at the same rate as the former. The increase in the amount of chlorides removed from the soil is, on the other hand, at nearly the same rate as the increase in the drainage. Expressing in figures the average results of the three gauges, the increase of drainage in these two extreme seasons is from 100 to 268, the increase of chlorides from 100 to 252, and the increase of nitrates from 100 to 182. As the rain which produces the increased drainage also supplies the chlorides, it is easy to understand why both drainage and chlorides should increase at a similar rate. The rain, on the other hand, supplies but an insignificant amount of nitrates, and only up to a certain point increases the rate of nitrification in the soil; the larger amount of nitrates removed by heavy rain is thus in great measure simply due to the more thorough washing of the soil.

he quantity of the nitrates removed from the soil depends .tly on the amount of drainage, and as this has been very e during the last four years, it is impossible to say ːr, on the whole, the amount of nitrates yielded by the ;auges is, or is not, diminishing. It is, of course, how-robable that the production of nitrates is slowly becoming ıd that in the earlier years of the experiment the amount ıed in the drainage-waters was even larger than at :.

large quantity of nitrogen as nitrates removed per acre by .inage-water is a fact of great interest. The figures at the Table XXXIV. (pp. 72–3) show that the annual amount ogen as nitrates removed in the drainage-water was, on rage of four years, 45·51 lbs., 36·32 lbs., and 43·59 lbs. :ively from the three drain-gauges, the mean of all being lbs., equivalent to 268 lbs. of ordinary nitrate of ı. If we suppose that the drainage-water contained at ne time 0·5 part of nitrogen per million in the form of c matter and ammonia, we shall have a total of 43·77 lbs. quantity of nitrogen removed in one year from an acre of ped soil for 17·281 inches of drainage. Such a quantity ogen is equal to that contained in an average crop of or barley; its loss to the soil in the drainage-water is thus er of grave importance. Are we to suppose that a similar ːpt as bare fallow for an entire year in ordinary agricul-ractice would have suffered a similar loss? The question resolves itself into two: 1. Would the production of s be similar in the two soils? 2. Would the loss by ge be equal?

experimental soils being supported on perforated iron would, during dry weather, be aërated from below; the ls would thus be more freely exposed to air than could ı in an ordinary field soil. On the other hand, the gh tillage which accompanies an agricultural bare fallow ːxpose the surface-soil of the field to the action of the ɔhere more fully than can take place in the drain-gauge. ıpply of oxidisable organic matter must also now, after ars of exposure to the atmosphere and washing by rain, ısiderably less in the soils of our drain-gauges than in which has recently been manured and cropped.

ards the end of September 1878 the soil and subsoil of plots in two of the experimental fields at Rothamsted, had been left as bare fallow all the summer, were sampled, e quantity of nitrates they contained determined. To ɔth of about 18 inches they contained respectively 34 lbs.,

36 lbs., and 49 lbs. of nitrogen in the form of nitrates. The first two soils had received no nitrogenous manure for a great many years, and were probably in a state of greater exhaustion than the soils of the drain-gauges; the third had received nitrogenous manure, but had grown two crops since its application. In each case the crop preceding the fallow had been barley or wheat, and as these crops are known to remove nitrates very thoroughly from the soil, we may fairly conclude that the nitrates found were mainly the result of nitrification during the last twelve months. The amount of nitrate actually found would not, however, represent the whole produced, some must have been already lost by drainage. Indeed, during the six summer months of 1878, about 17 lbs. of nitrogen in the form of nitrates had been removed in the drainage-water of the 20-inch drain-gauge.

With this evidence before us, we are disposed to conclude that nitrates equal to 50 lbs. or more of nitrogen per acre may be produced in a single year's bare fallow of the arable soil at Rothamsted.

With regard to the loss which a soil under bare fallow would suffer by drainage, we must recollect, in the first place, that the rainfall during the four years' experiments with the drain-gauges just quoted was far above the average, amounting in fact to nearly 33 inches per annum; the drainage has consequently averaged 17·281 inches per annum, while with the normal Rothamsted rainfall the drainage would probably be only 10·92 inches, and with a rainfall of 25 inches but 7·62 inches. With a smaller drainage the loss of nitrates from the soil would considerably diminish, though not in the same proportion as the diminution in the drainage, as with a less rainfall the drainage-water would become stronger. We have one whole year of moderate drainage within the period of our determinations; in this year, 1879–80, the mean drainage was 9·808 inches, and the mean quantity of nitrogen as nitrates removed in the drainage-waters 31·78 lbs. per acre.

In a field of good natural drainage, with a soil of the same physical characters as our drain-gauge soils, we should expect the amount of drainage to be nearly the same when both were under bare fallow. It, however, by no means follows that, with an equal production of nitrates, and an equal drainage, the soil exposed to a one year's fallow would lose as large a quantity of nitrates as the soils of the drain-gauges. The average amount of nitrates lost by the drain-gauge in a year may perhaps fairly represent its annual production; but in order to *part* with this amount it must itself contain much more, as the soil is never

time thoroughly exhausted by drainage.* Unless, therefore, production of nitrates is far more active in the field than he drain-gauge, the amount lost during the first year of w would be much less than that passing from the drain-ge. Again, nitrates being produced chiefly in summer time, ordinary bare fallow suffers only from autumn and winter nage, and not from that of the whole year.

hough for the reasons just given the loss of nitrates by nage may be considerably less in an ordinary agricultural w than in our own drain-gauge experiments, the loss must rly be a very serious one whenever the season is wet. Bare w can only be thoroughly successful in a dry climate. ler such circumstances the active production of nitrates ch takes place in a fallow will doubtless greatly increase fertility of the soil for the succeeding crop. In a wet climate practice of bare fallow must result in a rapid diminution of nitrogen. The influence of cropping on the loss of nitrates lrainage will come under notice in Part III. of this paper. have already, however, had illustrations of one mode in ch a crop will greatly diminish such loss, namely, by largely easing the amount of evaporation, and thus diminishing the unt of drainage.

T III.—THE DRAINAGE WATERS FROM LAND CROPPED AND MANURED.

i the first paper on the Rothamsted Field Experiments, pub-ed in this 'Journal' in 1847, it was shown that a consider- part of the nitrogen applied as manure was not recovered ie increase of the crop produced.† Later determinations of quantity of nitrogen remaining in the soil after a long course ianuring showed that only a comparatively small proportion ie missing nitrogen could be accounted for by accumulations iin the soil.‡ The conviction gradually increased that the of nitrogen thus observed might be to a great extent due he washing out of nitrates from the soil by rain.§ An

Of the large amount of nitrates contained in the drain-gauge soils we get idea from the fact that the 20-inch gauge parted with over 62 lbs. of gen per acre in 1878–9, and still was far from being exhausted.

See also the following more recent Rothamsted Reports in this 'Journal' n the Growth of Barley by different Manures, continuously on the same ; and on the position of the crop in rotation," 1857, pp. 524, 528-531; and ort of Experiments on the Growth of Barley for 20 years in succession on ame Land," 1873, pp. 328–331. Also, "On the Annual Yield of Nitrogen re in Different Crops;" 'Report of British Association,' 1858.

ee the Paper "On the accumulation of the Nitrogen of Manure in the " 'Report of British Association,' 1866.

ee the Second Report on the Growth of Barley, already mentioned, pp. 45; also "Our Climate and our Wheat Crops;" this 'Journal,' 1880, p. 199.

excellent opportunity of testing the soundness of this conclusion was afforded by the experiments in Broadbalk Field, this field having been for many years cropped with wheat, manured with various kinds of manure, and being furnished with a complete system of drain-pipes. The investigation of the drainage-waters from this field commenced in 1866. Before speaking of the results we must briefly describe the conditions of the experiment.

1. *The Experimental Field.*

Broadbalk Field contains about 13½ acres of arable land, of which only 11¾ acres are now under exact experiment. The field lies in "lands," each 4⅛ yards wide; two adjoining lands form the two halves, *a* and *b*, of one plot. Both on the extreme right and left of the field there are, however, a few plots consisting of one land only. The length of the principal plots (Nos. 2–19) is 352 yards; the area of each "land" is thus $\frac{3}{10}$ acre.

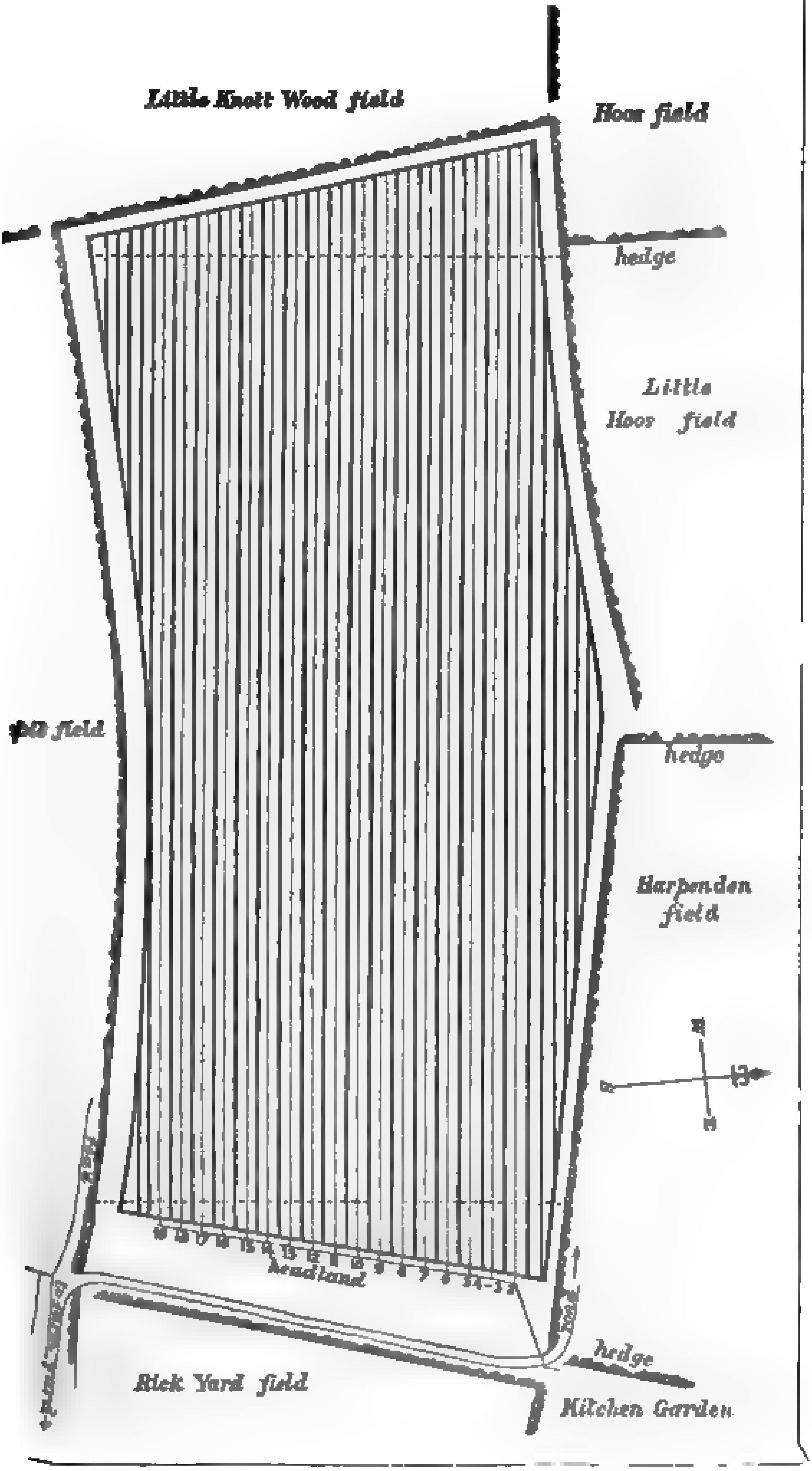
The field was laid with drain-pipes in 1849, but without, at that time, any intention of employing them for experimental purposes. A drain was laid down the centre of each plot, from Plot 2 to Plot 18, the course of the drain lying under the furrow, separating the two lands of which each plot consists. A drain was also laid along the outer edge of Plot 19, which consisted at that time of one land only. The drains were thus 8¼ yards apart.

A plan of Broadbalk Field will be found on the opposite page. The thick parallel lines represent the side-boundaries of the plots, the lines across the field show the end-boundaries; no manure has been applied for many years above or below these lines. The dotted parallel lines show the system of drain-pipes. The number of the plot to which each drain belongs is shown at the lower end of the plan.

The general slope of Broadbalk Field is from west to east. The total fall of the drain of Plot 19 amounts to 12 feet 1½ inches; on the other side of the field, in the middle of Plot 2, the fall is 16 feet 9 inches in 352 yards. The inclination is but small in the upper part of the field, it occurs chiefly in the lower five-eighths of its length. The drains deliver entirely at the lower end of the field. At this end there is a small fall of 1 foot 9¾ inches from Plot 19 to Plot 2.

The drain-pipes employed were those known as the "horseshoe and sole;" the internal diameter of the drain is about 2 inches. The drains lie generally about 2 feet below the furrow under

Plan of Broadbalk Field, showing the system of Drain-pipes.



which they are placed; the depth is greatest towards the middle of the field, where it reaches about 2½ feet. The lower ends of the drains were originally connected with a main drain, 4 inches in diameter, lying across the headland at the bottom of the field; by this main drain the water was conveyed to a ditch at a considerably lower level.

Early in December 1866 the connection of the drain-pipes from Plots 2–16 with the main drain was severed, and small pits dug at the previous points of junction. The drain-water flowing from the pipes was now discharged into the pits, and samples could be collected from the pipes before the water was carried off by the main drain. The ends of the pipes from Plots 17–19 were not uncovered till November 1878.

The arrangements just described for collecting the drainage-waters were at first by no means perfect. During heavy rains a considerable amount of surface-water collected in the intermediate furrows* at the bottom of the field, chiefly towards the left-hand side; this was in extreme cases reinforced by a flood coming through the hedge from Saw-pit Field. To remove this surface-water a furrow was opened across the bottom of the field, starting at the hedge-green by Saw-pit Field, crossing the lower edge of Plots 19 and 18, and coming out on to the headland at the bottom of the field at the furrow separating Plots 2 and 1. After some time, the point of exit of this surface-drain was altered to the furrow separating Plots 3 and 2, it being thought that the drainage from Plot 2, which is always very scanty, was affected by the water thus brought over its drain-pipe. In the autumn of 1877 a surface-drain was constructed along the hedge by Saw-pit Field; and in the following autumn a large soak-pit was dug in Saw-pit Field; both with the object of protecting Broadbalk from flood-water. This object is now fairly accomplished. Surface-floods occur at present only from the melting of snow, or in storms of very exceptional character.

Another difficulty at first experienced was due to the small outfall provided by the drains. In heavy rains the pits into which the drains delivered quickly filled above the level of the pipes, and it was necessary to bale out the water in each pit before a collection from the pipe was possible. The water filling any pit being to some extent a mixture of the drainage-waters of all the plots lying to the left of it (the same main drain passing through all the pits), there was some danger of

* In heavy rain surface-water runs down the alternate furrows in considerable quantity, it rarely appears in the furrow occupying the centre of each plot, owing to the action of the drain-pipe beneath.

the drainage-waters being contaminated by the waters from other plots, and it was necessary, after baling the water out of each pit, to allow the pipe to run for some time before a trustworthy sample of water could be collected.

These arrangements are now much improved. The surface-drain running across the bottom of the field has been abolished; the alternate furrows, forming the boundaries of each plot, have been prolonged on to the headland, and connected by a 4-inch pipe with the main drain, thus removing the surface-water between each plot without passing it over the drain-pipes of other plots. The main drain has also been considerably enlarged, and relaid 1 foot below its former level. In consequence of this improvement the outfall-pits now never fill with water, and no difficulty is experienced in collecting at all times the drainage-water flowing from the pipes. These improvements were completed in February 1879.

It has been necessary to go into this detail because the value of the analyses of the drainage-waters entirely depends on these waters truly representing the drainage of particular plots of soil. It will be gathered from what has just been stated, that the earlier collections of waters were somewhat more liable to occasional contamination, both from surface-water, and from mixture with the waters of adjoining plots, than the collections made since February 1879.

Since the opening of the drains, a careful record has been kept of the dates on which each drain ran, and of the size of the flow when observed. In the driest season experienced (October 1873 to September 1874) the largest number of runnings recorded for any pipe was three; while in the wettest season (1878–9), the largest number of runnings from one pipe was forty-six. In Table XXXVI. is given the total number of daily runnings of each drain-pipe during fifteen years.

In summer time, while the field is covered by the crop, drainage rarely takes place. A commencement of running is usually made in October, and the drainage reaches its greatest vigour in December and January.

It will be noticed that the drains from the various plots do not run with equal frequency. Plots with a similar winter drainage show a dissimilar summer drainage if one bears a heavier crop; the relative amount of drainage from two plots is even in some cases reversed at different seasons of the year, the plot having the greater winter drainage giving a less summer drainage by reason of its larger produce. Such facts will be seen by comparing the records of drainage for Plot 3&4 with those for Plot 7; those for Plot 5 with Plot 6; and Plot 11 with Plot 13. The average crops grown on all these plots will

TABLE XXXVI.—NUMBER of DAYS that each DRAIN-PIPE ran in BROADBALK FIELD during 15 YEARS, 1867–81.

	Plots.														Mean per Plot.
	2.	3&4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	
January	19	39	49	48	47	44	41	38	44	50	45	33	30	27	40
February	8	27	30	34	27	27	27	26	30	29	30	20	18	19	25
March	2	13	12	13	10	9	9	9	10	11	11	4	6	6	9
April	2	12	14	12	11	10	9	10	10	11	11	9	6	7	10
May	1	6	7	6	5	4	6	4	6	5	4	3	4	4	5
June	3	10	11	12	6	8	4	5	9	7	7	3	3	2	6
July	1	8	9	8	5	5	5	6	8	7	6	5	4	5	6
August	1	6	6	6	6	5	5	6	6	6	6	3	4	6	5
September	2	7	8	6	4	4	4	7	7	5	4	3	3	3	5
October	8	21	20	22	16	14	15	17	22	18	17	10	11	12	16
November	12	35	39	40	31	30	27	25	34	35	37	23	27	25	30
December	13	43	51	58	50	47	38	40	59	51	52	32	26	24	42
April—September	10	49	55	50	37	31	33	38	46	41	38	26	24	27	36
October—March	62	178	201	215	181	171	157	161	193	194	192	122	118	113	161
Total 15 years	72	227	256	265	218	202	190	199	239	235	230	148	142	140	197
Mean per year ..	5	15	17	18	15	13	13	13	16	16	15	10	9	9	13

ound in Table XXXVII. (p. 87). In all these cases the ter evaporation by the heavier crops dries the soil, and thus inishes the drainage.

'here are considerable differences in the rate of running of the s of some of the plots which are quite independent of any rence in the crop; such differences are best seen by looking he total runnings recorded for the winter months, October Iarch, as no irregularity is then introduced from differences he bulk of the crop.

t will be seen that the drain-pipe from Plot 2 runs with far frequency than any other; the running is only for a short e, and the water is always turbid. This plot has received ons of farmyard-manure each year since 1844. A great imulation of organic matter has thus taken place, which has tly increased the power of the soil to hold water. In a r on the "Effects of the Drought in 1870 on some of the erimental Crops at Rothamsted," published in this 'Journal' 871, determinations are given of the water contained in the of three of the plots in Broadbalk, both in a dry summer y 1868), and when in a state of winter saturation (January 9). In the latter condition the three soils contained the wing amounts of water, expressed in tons per acre, to the h of 3 feet from the surface.

	Plot 2. Farmyard Manure.	Plot 3. Unmanured.	Plot 8. Ammonium-Salts and Mineral Manure.
	Tons.	Tons.	Tons.
Water in saturated soil ..	1610	1396	1549

'he soil of Plot 2 thus contained, when saturated, 214 tons e water than the soil of Plot 3, and 61 tons more than soil of Plot 8; quantities corresponding to 2·12 and 0·60 ies of rain respectively. The small amount of pipe-nage from this plot is thus to some extent explained. The n-pipe of Plot 2 has been opened to ascertain if any ob-ction existed, but none was found. In consequence of the discharge of drainage-water from Plot 2, a series of glass les has been connected with the end of the drain-pipe; a harge occurring at any time is thus preserved.

is difficult to account for the very different rates of running ome of the pipes. The drains from Plots 2 to 13 must a fall of about 16 feet in the length of the plot; from Plot 14 9 the fall diminishes to about 12 feet. All the plots ing most frequently lie in the former group. Most frequent

or longest running does not, however, always imply the largest discharge. A study of the records that have been regularly made of the size of the streams issuing from the different pipes would show that the largest discharge is from Plots 13, 17, 3&4. Next in order stand Plots 11, 18, 12, 6, 5, which appear to be very equal. The third group is formed of Plots 15, 16, 14. The fourth group consists of Plots 10, 7. The fifth of Plots 9, 8. Last of all come Plots 2, 19. The amount of water passing off by the drain-pipes in the case of the fifth group is perhaps two-thirds of that discharged by the first group of plots; this will probably represent the extreme range of variation, if we except Plots 2 and 19. The cause of some of these differences apparently admits of explanation; thus a part of the water from Plots 8, 9, 10, 14, is probably intercepted by dells, through or alongside which the drain-pipes pass. The character of the subsoil is also an important factor. Where the subsoil is exceptionally stony, as is the case in certain places in the field, the water conveyed by the drain may be more or less lost, this loss of water being greatly facilitated by the character of the drain-pipes used.

The account just given of the mode of running of the drains in Broadbalk Field will seem strange in many particulars to those who are familiar with the working of deep drains on heavy clay land; the drains on such land will usually run uninterruptedly throughout the winter, while the drains in Broadbalk Field continue running only a few hours after rain has ceased. The cause of difference lies in the fact that the Broadbalk drains are comparatively near the surface, and that any accumulation of subsoil water is prevented by the chalk which underlies the soil at a depth of about 10 to 14 feet from the surface. The drainage-waters from Broadbalk are thus a discharge of the water percolating through the soil, while the drainage from the deep drains in heavy land is mainly supplied from a reservoir of subsoil water.

We have now to describe the manures applied to the various plots in Broadbalk Field. The manures applied, and the average produce obtained during the last fifteen seasons, 1866–7 to 1880–81, through more or less of which the investigation of the drainage-waters has continued, and during the 30 seasons (1852–81) of nearly uniform manuring year after year, will be found in Table XXXVII. In the case of Plots 2 and the manuring has remained unaltered since 1844, the date of the first experimental wheat-crop.

The dressing of "mixed mineral manure" contains in every case 3½ cwts. of bone-ash superphosphate, 200 lbs. of commercial sulphate of potassium, 100 lbs. of sulphate of sodium (salt-cake), and 100 lbs. of crystallised sulphate of magnesium

BLE XXXVII.—MANURING and PRODUCE of BROADBALK WHEAT-FIELD, per ACRE, per ANNUM.

MANURES.	30 Years, 1852–1881.		15 Years, 1867–1881.	
	Dressed Corn.	Total Produce (Corn and Straw).	Dressed Corn.	Total Produce (Corn and Straw).
	Bushels.	lbs.	Bushels.	lbs.
14 tons Farmyard-Manure	33½	4696	31½	5304
Unmanured	13½	2169	11¼	1726
Mixed Mineral Manure	15½	2443	12¾	1984
200 lbs. Ammonium-salts and Mixed Minerals	24	4006	20¼	3348
400 lbs. " " ..	32½	5769	28⅛	5013
600 lbs. " " ..	36	6737	33⅛	6219
550 lbs. Nitrate of Sodium and "	36⅛	6903	36¼	6920
550 lbs. Nitrate of Sodium, alone	23½	4293	20¼	3587
400 lbs. Ammonium-salts, alone..	21⅞	3687	18	2904
" " " and Superphosphate	26	4402	22¼	3716
" " " and Sulph. Sodium	31	5301	26½	4493
" " " and Sulph. Potassium	31½	5561	28⅜	4964
" " " and Sulph. Mag.	31⅜	5424	27⅞	4716
" " " and Mixed Minerals [1]	31⅛	5396	28½	4826
Unmanured [2]	25½	4678	13⅜	2131
Mixed Mineral Manure [3]	[4] 15¾	2574	[4] 13¼	2090
400 Ammonium-salts [3]	[5] 29¾	5171	[5] 27	4619
1700 lbs. of Rape-cake [6]	28½	4758	25¼	4025

1872 and previously, 400 lbs. sulphate of ammonium were applied on half and on the other half 300 lbs. sulphate of ammonium and 500 lbs. of rape-h halves receiving mixed mineral manure. Up to 1872 the superphosphate plot was prepared with hydrochloric acid.
m 1852 to 1864 this plot received 800 lbs. ammonium-salts, with the mixed manure.
manures on these two plots alternate each year.
rage of mineral manure, alternating with ammonium-salts.
rage of ammonium-salts, alternating with mineral manure.
1878 and previously, 300 lbs. sulphate of ammonium, 500 lbs. rape-cake, erphosphate, the latter made with hydrochloric acid.

* The same quantity of superphosphate (3½ cwts.) is applied l cases; but an increased amount of the sulphates of sodium magnesium is applied to Plots 12 and 14, the quantities of two sulphates being respectively 366½ and 280 lbs.
he "ammonium-salts" are in every case a mixture of equal s of the sulphate and muriate of commerce. The 400 lbs. nmonium-salts, the 550 lbs. of nitrate of sodium, and the) lbs. of rape-cake are believed to contain approximately the e quantity of nitrogen; the rape-cake is somewhat variable omposition.
Table XXXVIII. will be found an estimate of the quan-of each substance annually applied in manure, expressed

In 1858, and previously, 300 lbs. of sulphate of potassium, and 200 lbs. of ate of sodium were employed.

ANTITIES of each CONSTITUENT of MANURE annually applied to BROAD (and in some cases earlier) to 1880–1, in lbs. per ACRE.

Plots.													
5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.		16.	A n S
										1859–72.	1873–81.		
0	100	100	100	50	..	..	..	100	..	103	100	..	
1	41	41	41	212	..	1	147	1	1	41	41	..	

›s. per acre. The estimated composition of the farmyard-ure applied on Plot 2 must be taken as approximate only. small quantities of magnesia and soda credited to Plots l3 are contained in the bone-ash used.

ll the manures, except the dung, are sown broad-cast; ng sowing two screens are carried along the boundaries of plots to prevent the manure being carried beyond its proper ts. The autumn manures are ploughed or harrowed in as as possible after sowing, the wheat being drilled afterwards. spring manures are top-dressed.

he farmyard-manure, the superphosphate, and the sulphates ›otassium, sodium, and magnesium, have always been ied in the autumn. During the first six seasons in h the drainage-waters were collected the ammonium-salts applied on all the plots in the autumn, and had been ›rmly so applied for many years previously. Since 1872–3 mmonium-salts have been applied on Plot 15 at a different from the other plots. In the five seasons, 1872–3 to –7, Plot 15 received its ammonia in the spring, the other in the autumn. Since this time the order has been rsed, Plot 15 receiving ammonium-salts in the autumn, and he remaining plots in the spring. The nitrate of sodium always been applied in the spring.

s the dates of sowing manure and of harvest are points h must be borne in mind in discussing the composition ıe drainage-waters, a summary of these particulars is given able XXXIX.

.E XXXIX.—Dates of Sowing Manures and of Harvest in Broadbalk Field, 1866–7 to 1880–1.

n.	Manures Applied.				Wheat Cut.
	Mineral Manures.	Ammonium-salts.		Nitrate of Sodium.	
		Plot 15.	Other Plots.		
7	Nov. 5–6.	Nov. 5–6.		Mar. 25.	Aug. 23–24.
8	Oct. 30–Nov. 1.	Oct. 30–Nov. 1.		„ 18.	July 22–28.
9	„ 28–31.	Oct. 28–31.		Apr. 1.	Aug. 16–18.
70	„ 30–Nov. 2.	Oct. 30–Nov. 2.		Mar. 25.	„ 5–12.
1	„ 18–22.	Oct. 18–22.		„ 23.	„ 21–23.
2	„ 16–17.	Oct. 16–17.		„ 7.	„ 16–17.
3	„ 17–18.	Mar. 25.	Oct. 17–18.	„ 25.	„ 15–19.
4	„ 27–28.	„ 19.	„ 27–28.	„ 19.	„ 3–11.
5	„ 20–23.	„ 23.	„ 20–23.	„ 23.	„ 16–21.
6	„ 29–30.	„ 24.	„ 29–30.	„ 24.	„ 8–19.
7	„ 16–17.	Apr. 11.	„ 16–17.	Apr. 11.	„ 18–24.
8	Nov. 2–3.	Nov. 2–3.	Mar. 14.	Mar. 14.	„ 1–10.
9	Oct. 14–15.	Oct. 14–15.	„ 10–13.	„ 10.	Sept. 4–17.
80	„ 22.	„ 22.	„ 9.	„ 9.	Aug. 14–20.
1	„ 15–16.	„ 25.	„ 12.	„ 12.	„ 8–11.
2	„ 27–28.	„ 27–28.	Feb. 23.	Feb. 23.	..

Waters of Land-Drainage.," comm
this 'Journal' in 1874, page 132.*

In Table XL. we have recalcu
the principal ingredients found in
series of waters, and have also gi
the drainage from each plot, ca
Dr. Voelcker's analyses.† The col
the first considerable running after
manures; the collection on April 2
same season, after the application
Plot 9. From want of space, th
matter (by ignition), oxide of iro
are omitted.

Dr. Voelcker's analyses are of
only ones giving a full account of
tained in the waters from the variou
postpone the consideration of the re
subject before us.

The next examination of the Bro
Dr. Frankland. He made in all 1
extending from Jan. 13, 1868, to F
collections, namely those on Jan. 5,
and on Jan. 19 and Feb. 26, 187
from nearly all the plots. The colle
and small runnings of the drains.
analyses of the waters collected on
The first of these collections

L.—Composition of Drainage-Waters from Broadbalk Field in parts per Million (Dr. Voelcker).

tal lid ter.	Lime.	Magnesia.	Potash.	Soda.	Nitrogen as:		Chlorine.	Sulphuric Acid.	Phosphoric Acid.
					Ammonia.	Nitric Acid.			
				January 13, 1868.					
·9	136·7	5·1	5·4	13·7	0·05	12·5	21·9	94·6	..
·7	102·0	4·6	2·4	5·9	0·15	6·7	14·6	25·0	..
·0	151·6	6·6	10·3	14·9	0·16	9·3	16·7	110·9	..
·0	179·6	9·1	8·6	10·3	0·02	17·0	36·6	119·6	..
·4	235·6	7·7	1·9	15·1	0·07	28·1	28·1	131·6	..
·7	247·3	8·0	3·9	14·4	0·07	31·0	62·6	119·3	..
·0	108·7	3·9	1·7	42·0	0·15	12·0	18·7	56·9	..
·9	208·9	7·7	2·0	7·4	0·08	25·3	45·9	59·3	2·00
·6	201·6	8·0	0·9	9·0	0·07	28·8	51·1	72·6	2·57
·6	234·7	5·9	3·7	34·4	0·05	30·1	57·4	136·3	2·14
·1	246·0	8·3	5·9	8·0	0·11	35·0	58·4	108·4	1·43
·0	270·3	16·1	0·7	8·1	0·06	37·7	60·6	133·4	1·29
·1	274·3	12·7	9·3	18·1	0·21	46·5	36·6	171·6	2·00
·6	112·3	5·9	3·7	4·1	0·09	13·5	17·7	25·4	1·29
				April 21, 1868.					
·1	85·1	6·7	1·0	9·6	trace	0·9	8·3	11·3	0·57
·3	95·1	6·6	2·9	11·1	none	1·4	9·3	37·4	1·46
·8	86·3	7·7	3·0	10·7	trace	1·9	10·4	34·7	0·90
·9	114·4	8·0	2·6	7·0	0·08	4·5	16·6	47·6	0·91
·9	102·3	15·1	1·9	4·4	..	6·0	19·7	58·4	0·17
·6	153·6	9·9	6·1	93·9	none	58·3	14·6	23·9	..
·5	111·1	7·4	0·9	5·9	0·09	10·1	17·7	38·7	0·90
·6	117·1	6·6	1·4	4·0	..	7·6	17·7	38·4	0·73
·4	138·3	7·1	2·9	16·9	0·50	1·7	7·3	39·7	0·36
·4	100·3	15·9	1·9	4·3	0·13	5·6	20·9	52·9	0·73
·6	157·3	10·0	1·4	5·3	..	6·7	22·9	66·7	0·73
·6	146·0	6·7	3·1	10·1	..	7·6	12·4	81·0	1·07
·7	102·6	5·6	4·1	8·6	0·06	5·9	14·6	26·4	0·54
			Mean of Five (or fewer) Collections.						
·1	147·4	4·9	5·4	13·7	0·16	16·1	20·7	106·1	..
·4	98·1	5·1	1·7	6·0	0 12	3·9	10·7	24·7	0·63
·0	124·3	6·4	5·4	11·7	0·13	5·1	11·1	66·3	0·91
·6	143·9	7·9	4·4	10·7	0·20	8·5	20·7	73·3	1·54
·4	181·4	8·3	2·9	10·9	0·07	14·0	26·1	90·1	0·91
·4	197·3	8·9	2·7	10·6	0·27	16·9	39·4	89·7	0·17
·9	118·1	5·9	4·1	56·1	0·24	18·4	12·0	41·0	..
·9	154·1	7·4	1·9	7·1	0·08	13·9	32·0	44·4	1·44
·9	165·6	7·3	1·0	6·6	0·17	15·3	31·6	54·3	1·66
·9	191·6	6·6	2·7	24·6	0·30	15·1	30·9	96·7	1·26
·3	201·4	9·3	3·3	6·1	0·16	17·4	36·6	86·9	1·09
·6	226·7	11·6	1·0	5·6	0·09	19·2	39·4	99·7	1·01
·3	201·1	7·9	5·3	14·3	0·11	24·2	24·6	123·9	1·54
·7	117·1	5·3	2·4	5·1	0·09	7·0	11·4	21·9	0·91

siderable quantities of nitric a
drainage-waters from the plots r
nitrate of sodium. This loss of n
to be, from an agricultural point o
ject most requiring a fuller inve
Rothamsted has therefore been chi
question. The examination of th
determination of the quantity of n
with qualitative testing for amm
methods employed were the same as
speaking of the analysis of the wa

By confining the examination of
tion of the two constituents just n
examine a far larger number of wat
been accomplished. The analyse
waters collected in 1876, eight
thirty-six series collected in 187
1879–80, and forty collected in 18
seasons, individual or mixed sam
running of the drains, have been
total number of samples analysed
part of these analyses were made by
summaries of the very numerous
body of the paper, but they are
Appendix Tables.

In considering the facts which th
Frankland, and our own more rece

TABLE XLI.—COMPOSITION of DRAINAGE-WATERS from BROADBALK FIELD in parts per MILLION. (DR. FRANKLAND.)

PLOTS.	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as:				Chlorine.	Total Hardness.
			Organic Matter.	Ammonia.	Nitrates and Nitrites.	Total Nitrogen.		
				JANUARY 5, 1872.				
2	512·0	4·52	1·41	0·17	25·9	27·5	33·5	321
3&4	344·0	2·17	0·57	0·02	13·1	13·7	14·0	206
5	482·4	1·59	0·60	0·01	14·2	14·8	14·5	357
6	701·6	1·57	0·52	0·01	27·8	28·3	43·0	500
7	862·4	1·94	0·65	0·01	47·4	48·1	68·5	590
8	1239·6	1·80	0·83	0·01	78·4	79·3	112·5	766
9	505·2	1·51	0·60	0·01	23·1	23·7	18·0	335
10	734·4	..	..	0·01	55·6	..	73·5	537
11	931·2	0·90	0·64	0·01	66·8	67·5	92·5	628
12	1016·4	1·09	0·47	0·00	57·7	58·2	80·5	681
13	1056·0	1·24	0·51	0·00	59·2	59·7	91·0	696
14	1059·2	1·63	0·54	0·01	57·8	58·4	95·0	711
15	1162·4	1·27	0·59	0·01	72·5	73·1	57·5	774
16	351·2	12·13	2·77	0·01	13·2	16·0	12·5	248
				MAY 18, 1872.				
3&4	165·0	1·50	0·24	0·00	0·3	0·6	10·5	180
5	238·0	1·35	0·20	0·00	0·7	0·9	7·5	218
6	363·0	2·03	0·29	0·00	0·5	0·8	11·0	297
7	318·0	1·67	0·32	0·00	0·6	0·9	19·5	277
8	381·0	1·97	0·52	0·04	0·9	1·5	16·0	303
9	381·0	1·80	0·53	0·00	16·5	17·0	12·5	242
10	347·0	1·39	0·32	0·00	9·4	9·7	20·0	262
11	396·0	1·28	0·28	0·00	8·3	8·6	23·0	329
12	439·0	1·72	0·31	0·00	4·1	4·4	21·0	400
13	484·0	2·19	0·51	0·00	3·2	3·7	21·0	360
14	478·0	2·47	0·41	0·00	2·3	2·7	21·5	373
15	426·0	2·26	0·47	0·00	2·2	2·6	9·5	363
				MEAN OF FIVE (OR FEWER) ANALYSES.				
2	312·8	4·57	1·08	0·14	9·2	10·5	18·8	192
3&4	209·3	1·51	0·34	0·01	3·8	4·2	10·1	169
5	333·6	1·88	0·44	0·02	4·2	4·6	10·3	238
6	493·0	2·04	0·48	0·02	9·5	10·0	26·3	340
7	592·4	1·84	0·49	0·10	17·7	18·3	41·7	400
8	681·8	2·15	0·65	0·06	23·4	24·1	50·2	425
9	382·9	2·10	0·61	0·02	13·0	13·6	13·0	228
10	476·7	1·68	0·51	0·04	21·2	21·7	42·2	329
11	554·9	1·35	0·41	0·03	23·4	23·9	45·6	392
12	639·6	1·47	0·40	0·02	20·2	20·6	41·6	425
13	674·3	2·15	0·67	0·02	21·5	22·2	46·2	454
14	662·6	2·21	0·54	0·03	20·3	20·9	46·0	446
15	562·9	2·63	0·77	0·02	17·6	18·4	21·1	397
16	281·1	5·61	1·34	0·01	6·6	7·9	10·8	206

Influence of the Character and Stage of the Running.

We have already called attention, when speaking of the waters obtained from the drain-gauges, to the existence of two distinct kinds of drainage-water in our clay soils, one which has come directly from the surface through small channels in the soil, and the other which consists of the general discharge of the saturated soil; this fact is of considerable help in explaining the variations in composition observed in the drainage-waters from the same plot. Supposing that the soluble matter in a soil is *equally diffused* throughout it, the drainage-water will be weaker in proportion as surface-water preponderates in the discharge. This surface-water will consist partly of the discharge from the upper layer of soil, and partly of little altered rain-water, both of these gaining access to the drains through the channels in the soil. This drainage from the surface will precede the general discharge from the mass of soil above the drain-pipe. The admixture of rain-water will be most considerable during heavy rain, when water accumulates on the surface of the land, as water will then stand over the heads of all existing channels. Drainage from the surface will cease soon after rain has stopped, the upper layer of soil being the first to lose its supersaturated condition. As the running at the pipe diminishes, the drainage-water will be successively furnished by lower and yet lower layers of soil, till the soil is no longer in a supersaturated condition above the drain-pipe.

Under the conditions assumed, it is clear that the drainage-water collected at the commencement of a running will be much weaker than that collected at the end. A collection made during a heavy, long-continued rain, when the drains are rapidly discharging, will also be much weaker than a collection made from the same soil when the rainfall is moderate, and the discharge contains a less proportion of surface-water.

This is exactly what we observe in studying the composition of the drainage-waters obtained after the soluble manures have become diffused throughout the soil. One would perhaps have expected that the soluble salts (chlorides for instance) applied to the land as manure would appear in gradually diminishing proportion in the drainage-waters, each succeeding discharge being weaker than the one preceding; this, however, is not the case. The soluble salts are indeed gradually removed in the drainage-waters, but weak discharges are followed by strong, and strong by weak, the composition of the
the amount of the ra
the stage of the runni

There is usually a distinction visible to the eye between an
utflow containing much direct channel water, and one consisting
wholly of the true discharge from the soil; the former is usually
nore or less turbid, the latter always clear. The direct channel-
water is, in fact, always turbid, save after hard frost, or shortly
after the application of the artificial manures. We owe to
W. Skey, and to Th. Schloesing, the observation that the
presence of various salts, especially salts of calcium, determines
the coagulation of the particles of clay. In Broadbalk Field
the drainage-waters from the plots receiving ammonium-salts are
especially bright for some little time after these salts have been
applied; nitrate of sodium does not produce the same result. The
reason of this fact is that ammonium-salts greatly increase the
amount of lime in the drainage-waters, the sulphate or chloride of
ammonium reacting upon the chalk of the soil, sulphate and
chloride of calcium being produced, while nitrate of sodium
produces no such effect.

An excellent illustration of the difference in composition of
turbid and clear waters is afforded by Frankland's analyses of
January 19, and February 26, 1873. On January 19 there was
small flow of the drains; all the waters were clear. The next
unning took place on February 26. There was again a small
ow, resulting from the thaw of snow; all the waters were turbid.
he mean composition of the dissolved matter in the drainage-
ater from Plots 7, 8, 10, 11, 12, 13, and 14 on these two dates
ill be found in Table XLII.

ABLE XLII.—COMPOSITION of CLEAR and TURBID DRAINAGE-WATERS from BROADBALK FIELD, in parts per MILLION. (DR. FRANKLAND.)

Date of Collection.	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as Organic Matter.	Nitrogen as Ammonia.	Nitrogen as Nitrates and Nitrites.	Nitrogen as Total Nitrogen.	Chlorine.
1873.							
n. 19 (clear) ..	543·9	1·21	0·39	·03	15·2	15·6	27·6
b. 26 (turbid) ..	311·3	2·96	0·78	·07	6·1	6·9	13·7

It will be seen that while the total solid matter, and especially
e nitrates and chlorides, are greatly diminished in the turbid
ater, the organic matter and the ammonia have greatly in-
eased. The excess of organic matter in turbid waters, and
e increase in the proportion of carbon as the turbidity
creases, have been already noticed when speaking of the

Slightly turbid	32
Turbid	28
Very turbid	6

The proportion of carbon to ni
from cropped land is seen to be ra
from a bare fallow (see p. 65).

As an illustration of the differ
waters at the commencement and
the next page the amounts of nitri
the drainage-waters collected on
and on the morning of the follo
lection was made about one hou
running; the collection next m
drains were ceasing to run.

The increase in the chlorides an
the running is here extremely str
on June 2 were all more or less
Plots 3&4, 5, 9, and 12–18. The
all clear. This year the ammonium
in autumn, and to all other plots i

We have already stated that th
increase in strength towards the en
cases in which the soluble salts are
throughout the soil; it applies, i
When soluble manures have recentl

TABLE XLIII.—CHLORINE and NITROGEN as NITRIC ACID in DRAINAGE-WATERS from BROADBALK FIELD collected near the beginning and end of a running, in JUNE 1879, in parts per MILLION.

Plots.	Manuring.	June 2.		June 3.	
		Chlorine.	Nitrogen as Nitrates.	Chlorine.	Nitrogen as Nitrates.
3&4	Unmanured	0·8	none	2·3	0·9
5	Mixed Mineral Manure	0·6	none	3·1	1·5
6	200 lbs. Amm. Salts and Mins.	12·6	0·9	23·6	4·0
7	400 lbs. " " "	22·3	3·0	43·0	6·5
8	600 lbs. " " "	38·9	9·3	58·4	13·8
9	550 lbs. Nit. Sodium and Mins.	2·2	12·0	7·6	31·7
10	400 lbs. Ammonium-Salts ..	34·8	16·2	61·4	25·7
11	Ditto, with Superphosphate ..	37·1	10·7	66·9	18·6
12	Ditto, ditto, with Sulph. Sodium	35·8	7·8	59·8	13·3
13	Ditto, ditto, with Sulph. Potass.	33·9	4·3	63·1	7·9
14	Ditto, ditto, with Sulph. Mag...	34·6	7·3	43·3	10·5
15	400 lbs. Amm. Salts and Mins.	4·5	3·2	12·1	7·9
17	Mixed Mineral Manure	2·5	none	7·3	1·5
18	400 lbs. Ammonium-Salts ..	29·7	3·9	56·7	7·7

frequent intervals while the drains were running, with the especial object of ascertaining if any alteration in the composition of the waters occurred. A selection of some of the more characteristic results recorded for Plots 12 and 13 during a single season will be found in Table XLIV. Numerous other hourly collections have been made, showing similar results.

The ammonium-salts were applied to Plots 12 and 13 on March 12, 1879. The first running of the drains occurred on April 7; the pipes had been running for at least an hour when the first collection was made; the size of the stream was then about two-tenths of the pipe. No rain fell during the collections; the waters were all clear. The result of the hourly examination made shows that both chlorides and nitrates had diminished to less than one-half of their first amount by the time the drains had ceased to run, eight hours after the first collection.

The next running took place on April 13. The pipes ran for at least an hour before the first collection at 2 P.M. The size of the stream at this time was about four-tenths of the pipe. The waters were clear. It will be noticed that the chlorides in the first collection at this date are much larger than they were at the end of the previous running, the drains being now fed by the discharge of a higher layer of soil; the chlorides also do not fall so low at the close as in the previous case, the soluble

„ [illegible] „	[illegible]·8	1[illegible]
„ 10 „	53·4	
„ 11 „	50·2	1[illegible]
„ noon	47·0	
„ 1 P.M.	43·4	1[illegible]
„ 2 „	40·0	
„ 3 „	37·6	11
„ 4 „	..	[illegible]
April 13, 2 P.M.	65·0	26
„ 4 „	59·0	21
„ 6 „	54·4	18
May 29, 7 A.M.	68·7	16
„ 10 „	73·3	17
„ 1 P.M.	68·6	17
„ 4.45 „	62·3	16
July 1, 10 A.M.	21·7	1
„ noon	30·1	2
„ 2 P.M.	33·1	2
„ 4 „	35·7	2
„ 6 „	36·2	3
„ 8 „	36·8	3
August 3, 8 A.M. ..	16·2	0
„ 10 „ ..	20·2	0
noon ..	22·6	0
„ 4 P.M. ..	22·7	0
1880.		

Plot 13; the subsequent collections were all clear. During the first three hours it will be seen that the waters became stronger, but that afterwards they became decidedly weaker. We are here perhaps at the turning-point for the season: the layer of soil richest in chlorides lies now not far above the level of the drains.

The runnings of these plots on June 2 and 3 have been already given (Table XLIII.); the succeeding runnings on July 1 and August 3, 1879, and February 17, 1880, are given in Table XLIV. These are by no means the only runnings which occurred during the season, which was very wet, they are selected as giving a fair idea of the condition of the waters at certain characteristic periods. It will be seen that from June onwards the chlorides in the drainage-waters tend to increase as the flow of water diminishes, the upper soil being now poorer in chlorides than the soil immediately surrounding the drain-pipes.

The nitrates, being salts nearly equally diffusible with the chlorides, generally rise and fall with them, though frequently in very different proportion. Cases, however, may occur in which the chlorides and nitrates are not distributed throughout the soil in the same manner. As nitrification takes place most actively in the upper layers of soil, a band of nitrates may be formed near the surface of a soil in which the chlorides are already tolerably diffused. In such a soil the nitrates may diminish in the drainage-water with a diminishing flow of the drains, while the chlorides increase. An excellent example of this is afforded by the runnings of Plot 15 on Nov. 15 and 16, 1880. Plot 15 had received its ammonium-salts on Oct. 25; heavy rain followed from the 26th to the 29th; the chlorides were thus washed into the lower layers of the soil before any considerable nitrification had taken place. On Nov. 15, when the drains next ran, the surface soil had become rich in nitrates, the chlorides occupying a much lower level. In three successive collections the nitrogen and chlorine found were, in parts per million, as follows:—

	Nitrogen as Nitrates.	Chlorine.
November 15, 4 P.M. ..	67·8	39·0
" 16, 8 A.M. ..	50·0	60·6
" 16, 2 P.M. ..	34·6	63·1

The nitrates thus fell very considerably towards the end of the running, while the chlorides as strikingly increased.

R. W.

Plot.	Total Solid Matter.	Lime and Magnesia.*	(
	Per Million.	Per Million.	Pe
2	367·2	123	
3&4	227·8	99	
5	329·8	132	
6	450·3	171	
7	542·4	207	
8	615·1	222	
9	405·7	126	
10	441·8	173	
11	490·4	197	
12	585·3	218	
13	609·3	232	
14	630·6	244	
15†	571·3	217	
16	284·6	120	

Two of the plots in Broadba
receive no manure. On Plot 3 & 4
manured since 1840; while the o
for the crop of 1851; Plot 16 v
of 1864. The drainage-water fr
much less solid matter in soluti
other plot in the field The mean
analyses (Table XLV.) shows a
227·8 per million in the drainag
284·6 in the water from Plot 16.
of this solid matter are calcium-sa

its of the drainage-water, the dissolved matter rising to
per million. The sulphate of calcium present in the
phosphate, and the sulphate of sodium, are the chief con-
nts of the manure which appear in the drainage-water:
lphates of potassium and magnesium also react on the lime
ned in the soil, and furnish a further supply of sulphate of
m to the water.

ien ammonium-salts are applied to the land, the quantity
tter removed in the drainage-water is much increased;
n the water from Plot 10, receiving 400 lbs. of ammonium-
alone, the dissolved matter reaches 441·8 per million.
ammonium-salts are added to the mixed mineral manure,
lid contents of the drainage-waters rises in proportion to
uantity of these salts applied. Thus in the drainage-waters
Plots 6, 7 and 8, to which 200, 400 and 600 lbs. of ammo-
-salts are applied, the mean proportion of total solid matter
pectively 450·3, 542·4, and 615·1 per million.

e solid matter removed from the soil by the agency of the
nium-salts consists chiefly of sulphate, chloride, and ni-
of calcium. Probably the whole of the sulphuric acid and
ne contained in the ammonium-salts unites with lime and
esia in the soil; the resulting salts being soluble, they
be removed, to a greater or less extent, in the drainage-
as soon as a sufficient rainfall occurs. The 400 lbs. of
nium-salts would be able to remove annually from the
n this way about 172 lbs. of lime.* The actual loss of
would, however, be somewhat less, as a part of the sulphuric
and chlorine of the ammonium-salts would be retained by
op. Loss of lime will also occur as nitrate of calcium.
onia is speedily oxidised to nitric acid in the soil; this
combines with lime and magnesia in the soil, and
es appear in the drainage-water. Supposing that the
of the ammonia were converted into nitric acid, and that
esulting nitrates were entirely lost by drainage, the soil
l suffer a further loss of about 172 lbs. of lime for 400 lbs.
monium-salts applied. On a cropped soil, of course, the
n this score would be greatly diminished, as the crop would
ilate a large part of the nitrates formed. The action of
nium-salts in impoverishing a soil of lime and magnesia
l always be borne in mind when their application to soils
n lime is in question.

* is amount of lime would of course not be removed in the first year of the
tion of ammonium-salts, unless the drainage were especially excessive.
ever, the soil became yearly richer in soluble calcium-salts, the drainage-
ould increase in strength, until at last the loss by drainage balanced the
receipt.

tions within the soil by which
lime or magnesia soluble.

From Plot 10 to 15 there is a
of lime contained in the water.
superphosphate of lime to Plot 1
by the sulphates of sodium, pot
to Plots 12, 13, 14; the two
greatest influence in removing
being to a large extent retaine
phuric acid passes into the drain

The steady increase in strengt
15 is, however, much greater th
above considerations, and is sh
stituents; the waters from Plots
among the strongest in the fiel
strength the water from Plot 8.
drainage from Plot 15 does not a
Table XLV. for the reason men
regard simply the five analyses m
their ammonium-salts in the aut
drainage-water from Plot 15 con
lime, and more total solid matter
the field. As there is no obvio
tion of the manure for this unus
water, the cause must be sought
ing the drainage at this part of
come again before us further on

agnesia only ranges from 3·5 to 5·5 per cent. of the lime, and ses or falls with it. Plot 14, which receives nearly three times much magnesia as Plots 5–8, is no exception, the magnesia the water, though the greatest in absolute quantity, being ll only 5·1 per cent. of the lime. Where sulphate of magium was applied (excepting on Plot 14) the amount of gnesia in the drainage alone, that is besides the smaller ount in the crops, was approximately the same as in the nure, but in the other cases the soil itself contributed not h less magnesia to the waters.

or the purpose of illustrating the annual losses of lime and nesia which the soil suffers by drainage, we will assume that annual drainage in Broadbalk Field amounts to 10 inches million lbs.), and that it has the composition shown by the n analyses of Voelcker and Frankland given in Table XLV. lime and magnesia annually lost by the unmanured Plot will then be 223 lbs.; by Plot 5, receiving only mineral nure, 297 lbs.; by Plot 9, receiving nitrate of sodium and a dressing of mineral manure, 284 lbs.; by Plot 10, receiv- 400 lbs. of ammonium-salts only, 389 lbs.; by Plot 11, iving 400 lbs. ammonium-salts and superphosphate, 443 lbs.; by Plots 6, 7, 8, 12, 13, 14, receiving an average of 400 lbs. monium-salts, with the sulphates of potassium, sodium, and gnesium in addition, a mean of 485 lbs. per acre. A reference Table XXXVIII. will show that the quantity of lime and gnesia in the usual dressing of mineral manure is 104 lbs., amount lost is thus greatly in excess of that applied to land. The estimates just given are probably rather below n above the truth.

The amount of phosphoric acid found by Dr. Voelcker in drainage-waters was very small. The determinations de were few in number, and the results display little reguity. It is, in fact, left uncertain whether the amount of osphoric acid is increased by the use of phosphatic manures, whether it is influenced by the addition of ammonium-salts. e mean of all the determinations gives 0·93 of phosphoric d per million of water. If we assume, as before, 10 inches as average annual drainage in Broadbalk Field (in recent wet rs the drainage would be much greater), the annual loss of sphoric acid by drainage would be 2·1 lbs. per acre.

The determinations of potash are much more numerous than se of phosphoric acid; they also display great irregularity. is quite evident, however, that where potash was applied in manure, the amount is distinctly increased in the drainage-ter. The drainage-waters from the six plots receiving no ash contain an average of 1·6, and the waters from the eight

phoric acid. The water from
contains a mean of 6·1 of soda
five plots receiving 100 lbs. of
contains a mean of 11·6 per mil
of sulphate of sodium are appli
24·6 per million. Where 550
applied (Plot 9), the soda in the d
million. As sodium-salts are v
power of soil for soda is very s
regular supply of soda there wi
nearly equal amount in the drai
soda annually assimilated by the
three only of the plots in Bro
per acre.

The soda found in the draina
plots will be derived from rain;
diffusion from the neighbouring s
the chlorides present in the rain
common salt, the rain analysed a
1877–80, would have supplied an
A part of the sulphates in rain ma

It is obvious that if the phospho
manure have not escaped to any s
water, the portion unused by th
up in the soil. In October 1865,
taken from eleven of the plots in
first, second, and third 9 inches

; what residue of each constituent of the manure should l in the soil, supposing no loss had occurred by drain- was found on making the calculation that the phos- acid applied as superphosphate was pretty fairly ›d for, the excess of phosphoric acid being found stored e first and second 9 inches of the soil, but chiefly in the)f the potash applied, a considerable amount was found oil, chiefly in the first 9 inches, but a large quantity d unaccounted for; as it was clear that very little had in the drainage-water, Hermann Liebig concluded that been converted into a silicate insoluble in acetic acid. ulphuric acid applied, only a small amount was found in . Of the soda, no excess was found due to the manures save in the soil receiving farmyard-manure. The sul- cid and soda, being diffusible bodies, had clearly been less completely removed in the drainage-water.

ıay obtain evidence of the retention or non-retention by or crop of many of the substances applied in the manure, aring the relative proportion of the constituents present in ure with the relative proportion of the same constituents 1 the drainage-water; if no constituent of the manure 1 abstracted by the soil or crop, we shall find that the ›nts of the drainage-water bear the same proportion to er as in the manure; while any assimilation by the crop, or ı by the soil, will lower the proportion of the constituents oropriated in the drainage-water. Thus, taking seven eiving phosphoric acid, the mean proportion of sulphuric hosphoric acid in the manures applied is 1000 : 194; but ainage-water from these plots the proportion is 1000 : 17, a large retention of the phosphoric acid. Again, taking lots receiving a full dressing of potash, we find that the lation of sulphuric acid to potash in the manure is 73 ; while in the drainage-water from these plots the rela- 1000 : 50, showing a consumption or retention of more r-fifths of the potash. On the other hand, the relation ıuric acid to soda in the manure of seven plots is 53 ;* while in the drainage-water the relation stands 71, showing that a little more sulphuric acid than soda ı taken up. In the manure of nine plots the relation of c acid to chlorine is 1000 : 367 ;* in the drainage-waters n the proportion is 1000 : 382, showing that rather lphuric acid than chlorine has been retained. Thus ıe phosphoric acid and potash are largely retained by

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ıking these calculations the estimated amounts of sulphuric acid, nd soda in the rainfall of the seasons in question, have been added to ties applied as manure.

acid than for chlorine.

We have examples both in
Frankland of the alteration in
waters at different periods of the
and in Table XLI. will be found
from all the plots in January, an
of spring. The drainage-waters
after the application of the man
manures (excepting the nitrate
October at the time to which th
drainage-waters are, in this case,
total solid matter dissolved in th
diminished, save in the case of P
dressing of nitrate of sodium in
strength as the season advances i
plots most heavily manured, and
unmanured land.

A nearer inspection of the figure
are not only weaker, but of a diffe
collected in winter. The dissolve
contains as large a proportion of li
the winter waters, and perhaps ra
lime and magnesia are differently
nitric acid, sulphuric acid, and chl
since the winter, and the lime is
by carbonic acid; the waters of t
nearly approach the waters from t

The remaining constituents of drainage-water that we have to nention, namely the chlorides, ammonia, and nitrates, bring us o the point at which we can make use of the additional facts ırnished by recent work at Rothamsted. As any detailed atements must be omitted for want of space, we can only asider the general facts which the results of the analyses ch.

Chlorine is an element of very little agricultural importance. e wheat-crops in Broadbalk Field assimilate very little of the rides applied in the manure; in the corn practically no rine is found; in the straw only a small and variable quan- - Regarded simply as plant-food, chlorides might easily be missed from consideration. For our present purpose, how-r, the chlorides have a special and very considerable im-tance. Chlorides and nitrates are both salts for which soil sesses apparently no chemical retentive power; they are held soil merely as in a sponge: their distribution in the soil is s regulated by the amount of rain falling on the surface, and the ordinary laws of diffusion. As the amount of chlorine lied to each plot in the manure is with a single exception ot 2) fairly well known, the proportion of chlorine contained the drainage-water becomes an excellent indication of the ent to which the soluble constituents of the manure have been shed out of the surface soil; it enables us to judge of the rela-e concentration of the water issuing from different pipes; it o indicates in certain cases whether a mixture of the drainage-ters has taken place. A good instance of the important lessons hich may be learnt from a series of chlorine determinations s been already afforded when considering the alteration in mposition of drainage-waters in different stages of their nning (Table XLIV.). Facts ascertained with regard to lorides will be equally true of the other soluble diffusible lts present in the soil.

In Tables XLVI. and XLVII. will be found a summary of the nount of chlorine, and of nitrogen, in the form of nitric acid, curring in all the principal runnings of the drain-pipes during ree years, November 1878 to October 1881. These years clude long periods of exceptionally high rainfall, in which the ains ran with unwonted frequency; they furnish, in all, instances 49 runnings in which nearly every pipe participated, and thus ord material for trustworthy averages, showing the relative aracter of the discharge from each plot. Excepting during e first 3½ months, the drainage system of the field was also r the whole of this period provided with the later improve-ents already mentioned (page 83).

The *form of the Tables* is arranged so as to aid the study of the

production and removal of nitrates. The so-called "Winter" season begins with the sowing of the manures towards the end of October, and continues till the sowing of spring manures early in March. The so-called "Spring" coincides with the early growth of the crop, and concludes with the end of May. "Summer" is here reckoned as the period in which the crop has full possession of the land, and lasts from the beginning of June to the commencement of harvest. "Autumn" is reckoned from harvest to the date of manure sowing in October. For each of these four periods the analysis of the first and last general running of the drains is given, whenever such occurred; also the mean of all the general runnings in the period. The progressive alterations in the composition of the water are thus plainly shown.

In reading Table XLVI. we must remember that 100 lbs. of chloride of ammonium are applied to Plot 6, 200 lbs. to Plot 7, and 300 lbs. to Plot 8; while Plots 10, 11, 12, 13, 14, 15, and one of the alternating Plots 17 and 18, receive annually 200 lbs. Plots 3 & 4 and 16 are unmanured, and receive only the chlorine contained in the rain (see Part I. of this paper). Plots 5, 9, and 19 have no chlorine intentionally supplied in the manure, but the first two will receive a little, owing to the accidental impurities of commercial salts. The plot of the alternating series, 17 and 18, which receives the mineral manure, will have more or less of unwashed-out chlorides remaining in the soil from the application of ammonium-salts in the preceding year. Plot 19 will also contain some residue of its previous manuring with chlorides.

During the whole of the three seasons (1878–9 to 1880–81) included in the present tables, the ammonium-salts have been applied to Plot 15 in the autumn, and to all other ammonia plots in the spring. Of the alternating plots (17 and 18), Plot 17 received the ammonium-salts in the spring of 1878 and 1880; and Plot 18 in the spring of 1879 and 1881. The nitrate of sodium on Plot 9 has always been applied in the spring.

A glance at the results in Table XLVI. will show that the drainage-waters are all extremely rich in chlorides immediately after the application of the ammonium-salts.* The amount of chlorine in the first runnings of the plots receiving 200 lbs. of chloride of ammonium has averaged 89·7 per million during the three years in question, has frequently exceeded 100, and in one case reached 160 per million. The amount of chlorine in the drainage-waters reaches its minimum at the end of the

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* The first running in November 1878, given for Plot 15 (Tables XLVI. and XLVII.) shows far less chlorine, and less nitric acid than would be generally present in the first running of this plot. The running on November [illegible] is in fact not the first running, a large [illegible] unfortunately, we have no [illegible]

...E XLVI.—CHLORINE in BROADBALK DRAINAGE-WATERS at different SEASONS of ... YEAR, with the AVERAGE AMOUNT in THREE YEARS (1878-9 to 1880-1), in ...rts per MILLION.

...of Running.	Plots. 2.	3&4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
WINTER (October 15—March 10), 1878–9.																	
...ber 28	..	8·0	8·5	12·8	17·6	36·7	8·6	23·6	25·4	25·6	25·9	22·1	51·5	6·8	19·2	6·7	8·3
...y 16	..	3·6	4·0	8·0	8·4	14·6	4·2	10·8	10·1	9·9	11·4	11·0	23·9	4·0	10·8	4·2	..
...n 9 runnings	6·8	5·1	5·4	8·1	9·2	17·6	5·0	12·9	14·0	13·4	14·1	13·2	[illegible]	5·0	11·1	4·8	6·2
SPRING (March 11—May 30), 1879.																	
...7	..	4·4	4·9	63·0	102·4	91·4	12·4	70·6	61·2	83·4	101·4	119·2	14·4	4·7	8·0	180·0	..
...9	1·5	2·4	2·6	16·6	45·5	70·0	6·9	69·9	71·7	86·5	86·2	69·6	8·0	2·7	5·6	51·0	3·5
...n 3 runnings	1·4	3·6	3·8	40·5	69·6	73·7	9·0	66·6	60·1	71·3	82·2	98·4	9·8	3·6	6·0	95·8	3·4
SUMMER (June 1—September 3), 1879.																	
...9	6·4	2·3	3·1	23·6	43·0	53·4	7·6	61·4	66·9	59·8	63·1	43·3	12·1	..	7·3	58·7	..
...t 28	..	1·7	1·8	10·2	18·4	26·2	2·1	19·6	20·8	22·2	23·7	25·5	5·2	1·5	3·4	19·7	..
...n 9 runnings	6·3	1·3	1·5	11·8	20·5	30·7	3·1	29·6	31·9	30·7	30·8	31·4	6·0	1·9	3·9	26·0	1·1
AUTUMN (September 4—October 21), 1879.																	
...r 1	..	6·6	6·1	13·3	17·6	..	6·4	16·7	17·6	18·3	18·1	..	..	..	3·3	16·2	..
WINTER (October 22—March 8), 1879–80.																	
...16, 17, 19 (Mean)	13·7	8·9	11·7	15·0	17·6	22·6	10·7	16·7	20·5	21·4	23·0	21·0	129·3	10·0	9·9	21·7	16·1
SPRING (March 9—May 30), 1880.																	
...16	..	6·9	7·0	61·2	138·8	98·0	10·0	90·0	55·2	57·5	92·7	..	..	6·8	90·0	..	..
Autumn (August 14—October 24), 1880.																	
...mber 14	12·3	11·6	12·2	37·1	77·6	167·2	12·0	64·7	85·4	81·3	102·8	79·2	21·9	9·3	53·2	15·7	8·1
...ber 10	..	6·4	5·2	14·3	21·4	34·3	5·6	27·8	33·7	32·8	37·8	34·6	19·6	4·7	27·3	9·2	6·2
...an 6 runnings	8·0	8·2	7·7	18·9	41·4	66·3	8·3	38·2	52·9	49·8	60·1	48·0	24·4	6·7	42·3	11·6	7·2
WINTER (October 25—March 11), 1880–1.																	
..., 27, 28, 29 (Mean)	9·2	5·7	7·0	13·0	23·6	28·6	6·9	20·7	24·7	22·7	26·3	22·6	101·4	7·1	20·6	6·7	7·1
...., 5, 6, 7 (Mean)	2·7	4·3	4·4	8·1	9·8	10·8	4·2	9·0	9·8	6·7	9·4	8·7	14·2	4·2	7·1	4·6	4·1
...an 17 runnings	6·9	4·7	5·1	9·2	13·1	15·2	4·6	12·7	14·5	12·8	14·5	13·2	[illegible]	6·3	11·6	6·7	6·7
AUTUMN (August 8—October 27), 1881.																	
...gust 30	..	6·6	6·2	44·6	61·0	..	..	70·8	67·2	78·4	77·6	..	..	4·5	6·6	..	..
...ber 23	..	9·2	8·6	17·4	28·9	45·1	12·1	29·7	42·4	42·8	38·0	40·6	16·4	9·6	13·0	27·6	11·2
...an 4 runnings	..	7·7	7·6	35·9	45·0	45·1	12·1	43·5	62·3	69·5	62·3	40·6	16·4	7·6	12·1	27·6	11·2

AVERAGE OF THREE YEARS (November 1878—October 1881).

	Plots. 2.	3&4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15	16.	17 & 18. Am.	17 & 18. Min.	19.
...n of 49 (or ...) runnings)	6·1	4·9	5·2	14·0	23·1	30·8	5·7	24·2	26·1	25·7	28·9	27·8	32·5	5·1	25·4	[illegible]	[illegible]

TABLE XLVII.—NITROGEN as NITRIC ACID in BROADBALK DRAINAGE-WATERS at different SEASONS of the YEAR, with the AVERAGE AMOUNT in THREE YEARS (1878–9 to 1880–1), in parts per MILLION.

DATE OF RUNNING.	PLOTS.														
	2.	3&4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
WINTER (October 15—March 10), 1878–9.															
November 26	..	5·5	4·9	4·8	3·9	6·7	9·9	7 6	6·7	5 9	6 5	8·6	32·9	5 6	[illegible]
February 16	..	3·4	3·7	4·3	3·5	4 5	5 6	5·2	4·8	4·1	3·8	[illegible]	19 4	4 2	[illegible]
Mean 9 runnings	8·2	4 7	4·5	4·2	3·6	4·8	6 3	5 7	5·5	4 6	4·6	5·7	21·6	3·4	[illegible]
SPRING (March 13—May 30), 1879.															
April 7	..	3·6	2·9	22·5	39·0	30·6	68 9	45·4	41·8	25·4	29 4	33·0	9 6	3·6	[illegible]
May 29	3·6	1·6	1·1	3·7	9 3	19·7	32 7	27·1	21·3	16·6	11·2	16·1	8 4	1 5	[illegible]
Mean 3 runnings	3·6	2·5	1·9	14 2	25·3	28·4	44·9	34·5	28 0	23·0	24 9	31 6	6·7	2·2	[illegible]
SUMMER (June 1—September 3), 1879.															
June 3	2·2	0·8	1·4	4 0	6·6	13 8	31 8	25 8	18·6	8·3	7·9	10 5	7 9	.	[illegible]
August 26	..	none	none	none	none	0·6	2 6	5 4	0 9	0 6	0·4	0·8	1·6	none	[illegible]
Mean 9 runnings	1·4	0·1	0·2	0 7	1 4	2·6	9·1	11·6	5·6	3·7	1·9	3·4	[illegible]	[illegible]	[illegible]
AUTUMN (September 4—October 21), 1879.															
October 1	..	1·6	1·5	0 5	1·5	..	3·3	4·2	1 2	2·3	1·4	..	..	..	[illegible]
WINTER (October 22—March 8), 1879–80.															
Feb. 16, 17, 19 (Mean)	37 3	13·5	16·8	16·2	15 9	22 1	19·1	17·1	22 7	22·0	20 9	21·1	17·8	13 9	[illegible]
SPRING (March 9—May 30), 1880.															
April 16	..	4·6	5·6	16·0	32·2	27·6	65·7	22·9	19 1	21·3	30·5	..	..	6·8	[illegible]
AUTUMN (August 14—October 24), 1880.															
September 14	8·2	4 1	6 7	6 9	7·4	24·1	30·8	21·0	9·1	5·4	7·7	7 7	5·2	4·5	[illegible]
October 10	..	4·8	4·5	6 4	5 4	9·3	13·1	13 7	9·3	8·6	7·6	7·2	7·8	3·6	[illegible]
Mean 5 runnings	6·6	4 7	4·5	5 6	6 3	11·0	16·0	13·7	8·5	7 6	7 1	6·7	6·4	4·6	[illegible]
WINTER (October 25—March 11), 1880–81.															
Oct. 27, 28, 29 (Mean)	6·8	4·6	5·7	6·5	6·1	8·5	9·9	10·4	8 0	7·7	7 5	7·5	15·4	6·6	[illegible]
March 5, 6, 7 (Mean)	5·1	3·4	3·6	3 9	3·9	5·3	5 2	5·9	5·4	4·6	4 5	5·1	11 6	3·1	[illegible]
Mean 17 runnings	8·5	3·7	4·0	4·2	4 5	6 2	6·6	5 7	6·2	6·8	5·4	5 8	22·9	4·6	[illegible]
AUTUMN (August 8—October 27), 1881.															
August 30	..	0·9	1·4	1·9	4·1	–	—	16·1	6·8	2·3	2·4	..	..	4·2	[illegible]
October 23	..	8·7	9 5	13·3	18·6	23·0	21·8	16·2	19 6	13·2	14·6	15·0	13·1	6·6	[illegible]
Mean 4 runnings	..	6·2	6 3	8·6	11·3	23 0	21·8	16·5	12·4	8·5	8 6	15·0	13·1	5·4	[illegible]

AVERAGE OF THREE YEARS (November, 1878—October, 1881).

	PLOTS.														
	2.	3&4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	[illegible]
Mean of 49 (or fewer) runnings	7·5	3·9	4·2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

's drainage, immediately before the fresh application of ure. The minimum for Plot 15 occurs at the end .of mn, and that for the other plots receiving ammonia at the of winter.

he amount of chlorine present in the drainage-water at the od of minimum varies much, according to the amount of ing out by rain during the preceding year. The average unt of chlorine per million of water for seven plots receiving lbs. of chloride of ammonium was 10·3 on February 16, ; 20·1, for the mixed runnings of February 16, 17, 19, ; and 8·9 for the mixed runnings of March 5, 6, 7, 1881.

he amount of chlorine present in the drainage-waters at the rent seasons is extremely variable. Thus, on October 1, , the average amount of chlorine in the drainage-water of plots was 17·4 per million. On October 7, 1880, at 2 P.M., water from the same six plots, running at about the same , contained an average of 33·1 per million. On October 1881, four of the same drains ran, the water giving an age of 67·3 of chlorine per million. In these instances the igth of the water entirely depends on the amount of washing the soil has previously suffered.

Vhere dry weather has occurred after the application of the rides they may remain for many months above the level of drains, and when a running of the drains occurs, the water be as rich in chlorides as if they had been quite recently lied. Illustrations of this will be found in the runnings of tember 14, 1880, of February 16, 1880 (Plot 15), and of ust 30, 1881; see Table XLVI.

n the other hand, wet weather may greatly diminish the unt of chlorides in the soil, *even when the drains do not run.* s, Plots 7, 10, 11, 12, and 13 ran in August 1881, yielding rs rich in chlorides; they ran also in September and in the er part of October. Plots 8, 14, and 18 did not run before ber 23, but instead of yielding strong waters as the other did on their first running, they yield waters which are comparable with those of the now partially washed out 7, 10, 11, 12, and 13. The loss of soluble salts suffered le soil may thus be greatly in excess of the actual pipe-age.

nere is some indication that when a period of severe ing out is followed by a considerable interval of dry her, the drains on again commencing to run will yield r stronger than what they yielded on leaving off: compare runnings of August 28, and October 1, 1879, with of February 16, 1880; and the last runnings of Plots , 5, 9, 15, 16, 17, 19, in March 1881, with their first

runnings in the autumn of the same year; see Table XLVI. The increase of chlorine observed in these instances is much the greatest in the case of Plots 3 & 4, 5, 9, 17, receiving no chlorides. Supposing soluble salts have been washed below the level of the drains, it is natural to suppose that they would to some extent rise again by diffusion when the downward passage of water ceases, or that the water containing them in solution would be brought again to the surface by capillary attraction during dry weather. Simple diffusion would seem, in the examples just quoted, to have been the most active agent at work, the increase of chlorides being by far the most considerable in the case of plots very poor in this constituent; these plots have clearly, during the period of rest, obtained chlorine from the subsoil water.

The average figures at the foot of Tables XLVI. and XLVII. are the means of 49 analyses in the case of Plots 5, 6, 7, 9, 11, 12, 13; of 48 analyses in the case of Plots 3 & 4, 10, 17, 18; of 47 in the case of Plots 8, 15, 16; and of 43, 32, and 25 analyses in the case of Plots 14, 19, and 2 respectively.

The average amounts of chlorine are, with one exception, considerably below the earlier results of Voelcker and Frankland (Table XLV.). This is chiefly due to the very wet character of the last three seasons, and the consequent dilution of the drainage-waters.

Looking first at the plots receiving no chlorides in the manure, we see that the unmanured Plot 3 & 4 has given on an average 4·9, and the unmanured Plot 16, 5·1 of chlorine per million of drainage-water. Plot 5, receiving mineral manure, gives 5·2; and Plot 9, with nitrate of sodium, and a dressing of mineral manure on half its surface, gives 5·7 of chlorine per million.

The absence of any considerable amount of chlorine in the waters of these plots is the practical test that a mixture of drainage-waters has not taken place, but that each water fairly represents the plot to which it belongs. Plot 9 is most capable of acting as a test plot in this respect, lying as it does between two plots receiving chlorides, and one of them (Plot 8) receiving the largest amount of chlorides of any in the field. In earlier years the drain-water from Plot 9 occasionally contained much chlorine, probably through mixture with surface-water. In a running on December 8, 1868, Frankland found 60·0 per million of chlorine; in a running on April 11, 1878, we found 30·3 per million. Since, however, the improved drainage arrangements have been in action, the highest amount of chlorine found in the drainage for this plot has been 14·7 per million, which occurred on October 23, 1881, in a first running after a cessation of

inage for six months. That a small amount of diffusion of ıble salts does take place, whereby the unmanured plots are ıewhat enriched (diffusion is always from the stronger to the ıker solution) is probably true, but it is apparently limited imes of rest. So long as water is passing from above downrds, the manured or unmanured condition of the surface soil harply represented in the drainage-waters; but when active inage ceases, a very slow general diffusion will take place the soil continues sufficiently wet, the result being that the hest plots lose and the poorer plots gain somewhat in soluble ts.

The farmyard-manure plot shows but a small quantity of lorine in its scanty runnings, the amount, 6·1 per million, ceeding by very little the quantity in the drainage from the manured land.

Turning next to the average amount of chlorine from plots eiving chloride of ammonium, we may note that the difences between Plots 6, 7, and 8 are such as we should expect exist in the case of plots receiving respectively 100 lbs., lbs., and 300 lbs. of a chloride in the manure. If we uct the chlorine found for Plot 5 from that yielded by t 6, we obtain 8·8 as the increase of the chlorine due to lbs. of chloride of ammonium. Adding this figure to the rine found for Plot 6, we obtain 22·8 as the amount of rine proper for Plot 7; the figure actually found being 23·1. ding again 8·8 to 22·8, we obtain 31·6 as the amount of rine proper for Plot 8, the figure actually found being 30·8. e chlorine in the drainage-waters thus corresponds fairly h the chlorine applied in the manures, and we may consently assume that Plots 5 to 8 are really comparable in their ounts of drainage, though varying a good deal in the amount visible discharge at the pipes.

When we turn to the other plots receiving chlorides the ults are not so agreeable. Plot 10, indeed, receiving the ne amount of chlorides as Plot 7, gives also a very similar portion in its drainage-water; but Plots 11, 12, 13, 14, 15, 1 17, though receiving the same quantity of chlorides in their nure, yield, all of them, a considerably larger proportion in drainage-water, the quantity of chlorine rising on Plot 13 to ·9, and on Plot 15 to 32·5 per million. Plot 13, which eives the same amount of chlorides, and at the same time as t 7, thus yields one-fourth more chlorine in its drainageter. To what is this to be attributed? On turning to the orine determinations of Voelcker and Frankland (Table V.) we find the same increased proportion of chlorine in the

waters from Plots 10–14,* and the increase is in much the same proportion, an addition of one-fourth to the chlorine of Plot 7, giving a figure between those actually found for Plots 13 and 14. In the same Table we find that the lime and magnesia, and the total solid matter in the drainage-water participate in the increase. It is evident, therefore, that the drainage-waters at this side of the field are for some reason rather more concentrated than those collected at the other side. A reference to the plan of Broadbalk field (page 81) will show that the drain-pipes collect a portion of their water from an unmanured margin at the top and bottom of the field, and that the length of this margin is much greater at the right side than at the left side of the field, we should expect therefore that the pipes lying towards the left would deliver a rather stronger water than those lying towards the right. This, however, is not a sufficient cause for the difference observed, and we must assume, what is very likely, that a different proportion of surface water gains access to the pipes in different parts of the field. We have dwelt on this point somewhat fully, as it is important we should not attribute to the character of the manure an effect that may be merely due to the condition of the drain-pipes.

On Plot 15 the chlorides are applied in October instead of in spring, as on the other plots; this fact probably accounts for the increase of chlorine over that given by the adjoining Plots 13 and 14. The quantity of chlorine applied to all these plots has been the same, but it has been subjected to different seasons of drainage. The water from Plot 15 was indeed much poorer in chlorides at the end of the three years than at the commencement; while with Plots 13 and 14, and others receiving ammonium-salts in the spring, the contrary was the case. The two series of plots do not therefore admit of an exact comparison, and it will require a longer period of experiment to decide whether a larger amount of chlorine is generally contained in the drainage-water of the autumn-sown Plot 15 than in that of the spring-sown Plots 13 and 14; but from the results of Voelcker and Frankland we should expect that this will prove to be the case.

We turn now to a part of the subject of far greater practical importance, namely, the evidence which the drainage-waters of Broadbalk afford, both as to the production of nitrates in the soil, and their removal from it by drainage. We must bear in mind throughout this part of the discussion that the

* Plot 15 had at this time a different manure supplying less chlorine.

nitrates of the soil furnish the chief, if not the only, supply of nitrogen available to a wheat-crop.

The production of nitrates in an unmanured soil kept free rom vegetation has been discussed in Part II. of the present aper. It then appeared that the drainage-water collected uring the last four years from the soil drain-gauges contained n an average 10·7 parts of nitrogen, as nitric acid, per million water. The soil of these drain-gauges was ordinary arable il, undisturbed in its condition, and had been maintained for n years without manure or crop, and kept free from weeds.

When we turn to the nitrogen as nitrates found in the drainage-ters from the unmanured plots in Broadbalk field (Table LVII., p. 110), we find that the quantity is far smaller than in e water from the drain-gauges. The average figures for three ars given at the foot of the table, show that the mean amount nitrogen is 3·9 per million in the case of Plot 3 & 4, per-nently unmanured, 4·3 per million in the case of two plots eiving only ash constituents, and 4·5 in the case of the unma-red Plot 16. This much lower proportion of nitrates in the inage-water is doubtless partly owing to the great exhaustion the nitrogen of the soil by continuous wheat-cropping with-t manure, but is chiefly due to the fact that the crop actively propriates the nitrates formed in the soil. So complete is the propriation of nitrates by the wheat-crop, that during the ne of active growth, and for some time after, no nitric acid, a trace only, can be found in the drainage-water from several the plots in Broadbalk. This is well shown by the analyses Frankland of drainage-waters collected on May 18, 1872 able XLI.). In a later collection on June 11 of the same ar Frankland found no nitric acid whatever in the waters from ots 3 & 4, 5, 6, 7, 13. Similar results were found in the ana-ses made at Rothamsted of the waters collected during the nmers of 1878 and 1879.

In autumn nitric acid again begins to appear in the drainage-ters of the plots unmanured with nitrogen, and continues adily to increase if no serious loss by drainage takes place. en, however, with an excessive amount of drainage a certain portion of nitric acid is fairly maintained throughout the nter months, the production of nitrates generally keeping ce with their removal. The best illustration of the increase nitrates during autumn on land unmanured with nitrogen, is forded by the analyses of the drainage-waters from Plots 3 & 4, , 16 and 17, in August and October 1881. The maintenance f the nitrates during extremely wet winters is shown by the nalyses of waters during the winters of 1878–9 and 1880–1.

The considerable accumulation of nitrates that may occur in a dry winter is illustrated by the composition of the runnings in February 1880. All the analyses referred to will be found in Table XLVII. The general character of the waters at different seasons of the year is also illustrated by Table XLVIII.

The results yielded by the drainage-waters from plots receiving ammonium-salts are full of interest. Soil, as is well known, has a wonderful retentive power for ammonia, and this is one reason why ammonia is so seldom present in drainage-waters. In Voelcker's and Frankland's analyses of Broadbalk waters mere traces of ammonia were found, the amount being generally below that in ordinary rain-water. Our own examinations of Broadbalk waters lead to the same conclusion. We have, however, one instance in which ammonia was found in the drainage-water in considerable quantity. The usual dressing of 400 lbs. of ammonium-salts per acre had been applied to Plot 15 on October 25, 1880, and the manure ploughed in. Heavy rain occurred during the night of the 26th, so that on the morning of the 27th all the drain-pipes, save those of Plots 2 and 19, were found running. The water collected from Plot 15 at 6·30 A.M. contained nitrogen, as ammonia, equal to 9·0 per million; a later collection at 1 P.M., contained 6·5 per million. Rain still continuing, collections of water were also made on the two following days. On the 28th the water collected at 6.30 A.M. contained 2·5 per million of nitrogen as ammonia. On the 29th, at 10·30 A.M., the quantity was 1·5 per million. Ammonia is absorbed by soil from a solution of salts of ammonium, only when the soil contains a sufficient quantity of some base capable of uniting with the acids of these salts. The Rothamsted soil contains but little chalk; it was clearly unable to decompose the ammonium-salt sufficiently quickly to prevent loss of ammonia.

It is evident that the first result of the application of ammonium-salts to the Rothamsted soil is the chemical absorption of the ammonia; the acids of the ammonium-salts at the same time unite with the lime in the soil, and may be removed in the drainage-water. Thus the water mentioned above as containing 9·0 parts of nitrogen as ammonia, contained 146·4 parts of chlorine derived from the ammonium-salts. If the soil is sufficiently moist to allow of the reaction just described, nitrification of the absorbed ammonia will rapidly take place. In the instance before us nitrification had made distinct progress in 40 hours. On October 10 the drainage-water from Plot 15 contained 8·4 of nitrogen per million in the form of nitrates. On the morning of October 27, about 40 hours after the application of the ammonium-salts, the nitrogen as nitrates in the water had

en to 13·5 per million. By November 15, 21 days after wing the manure, the nitrogen as nitrates in the drainage-water d reached 67·8 per million.

The speed with which nitrification takes place is largely pendent on the amount of rain which falls after the ammonium-lts have been applied to the soil; water is required in the st place for the solution and distribution of the ammonium-t, and afterwards for the process of nitrification.

The product of nitrification appears to consist entirely of rates; traces only of nitrites have been found in the drain--waters from Broadbalk, and these are very possibly the lt of a reduction of nitrates previously formed.

t follows, from the quick nitrification of the ammonium-s, that the drainage-waters from plots receiving ammonia are est in nitrates shortly after the ammonium-salts have been lied. When the ammonium-salts are applied in March, as r are now on all plots, excepting Plot 15, the April waters are e strongest in nitrates. The mean of 27 analyses of waters ected in April from plots receiving 400 lbs. of ammonium-s in March gives 29·6 of nitrogen as nitrates per million of er. The maximum observed has been 45·4. The average of nitrogen as nitrates in the April waters thus corresponds -7 lbs. per acre, or to 42·8 lbs. of nitrate of sodium, for each of drainage.*

Vhen the wheat-crop commences its active growth the amount itric acid in the drainage-water greatly diminishes, and in case of some of the plots receiving ammonia the nitrates ppear altogether in summer time. The plot in which ates first disappear from the drainage-water is naturally t 6, as here only 200 lbs. of ammonium-salts are applied.

The various plots receiving 400 lbs. of ammonium-salts per acre er very much as to the extent of the reduction in the nitrates cted by the growing crop, the amount of reduction depend-entirely on the power of the crop to assimilate nitrogen. us on Plots 7 and 13, which receive both superphosphate and assium-salts, and thus furnish the crop in abundance with its st essential ash constituents, the power of the wheat to assimi- nitrogen is at its highest, and the nitrates may disappear gether from the drainage-waters in the course of the summer. complete opposition to this stands Plot 10, to which am-nium-salts are applied without any of the ash constituents of wheat-crop, and where, by long-continued treatment of this cription, the available ash constituents of the soil have become atly exhausted. On this plot the nitrogen applied is much

* One lb. of nitrogen will be contained in 6·1 lbs. of good nitrate of sodium.

The Rape-cake (Plot 19) and farmyard-manure (Plot 2) are both applied to the land in the autumn; in each case the drainage-waters are richest in nitrates in the winter. Nitrification, however, proceeds far more slowly with these organic manures than in the case of ammonium-salts, the amount of nitrates lost by drainage even in a wet winter is thus much less considerable. The rape-cake yields more nitric acid to the drainage-water than the farmyard-manure, and, when opportunity is given for accumulation, the amount of nitric acid may become very considerable, as in the case of the drainage-waters of February 16 and 17, 1880, when the nitrogen as nitric acid amounted to 33·0 per million for Plot 19. This considerable production of nitric acid from rape-cake is a proof, if one were needed, that the nitric acid in soil is not produced, as is sometimes asserted, solely from animal matter or ammonium-salts.

Table XLVIII.—Nitrogen as Nitrates in Drainage-Waters from Broadbalk Field at different Seasons of the Year, Average of Three Years (November 1878–October 1881).

Plot.	Nitrogen as Nitrates per Million of Drainage-Water.					Nitrogen per Acre per inch of Drainage.
	Spring Sowing to end of May.	June to Harvest.	Harvest to Autumn Sowing.	Autumn Sowing to Spring Sowing.	Whole Year	Whole Year.
						lbs.
2	3·6	1·4	6·0	9·5	7·5	1·70
3&4	3·0	0·1	4·8	5·0	3·9	0·88
5	2·9	0·2	4·8	5·5	4·2	0·93
6	14·7	0·7	6·0	5·4	5·4	1·22
7	27·1	1·4	7·3	5·4	6·6	1·51
8	28·2	4·0	13·5	7·5	9·3	2·10
9	50·4	9·1	15·0	7·8	12·5	2·83
10	31·6	11·4	12·7	6·9	10·7	2·42
11	25·8	5·8	9·0	7·7	9·0	2·04
12	22·6	3·7	8·0	7·1	7·9	1·73
13	26·4	1·9	7·3	6·7	7·6	1·72
14	31·6	3·4	8·1	7·5	8·5	1·92
15	6·7	2·9	7·5	28·1	19·3	4·37
16	3·3	0·1	5·3	5·6	4·5	1·02
17 & 18 Amm.	29·7	1·8	6·6	5·5	7·1	1·61
17 & 18 Min.	1·5	0·3	5·6	5·5	4·3	0·97
19	3·7	0·5	7·7	14·0	10·4	2·35

In Table XLVIII. is given a summary view of the nitrogen as nitric acid present in the drainage-waters of the various plots at different seasons of the year, based on the analyses made at Rothamsted during the last three years. The figures are of great interest; they should not, however, be taken as more than indications of the general truth. This is [illegible]

nembered in dealing with the figures given for the autumn riod. The analyses made of autumn waters refer mostly to ters following *dry* summers, not that summer which furshed the analyses of summer waters. Although, therefore, it quite true that the amount of nitrates rises in autumn in all ses where they have been much reduced in summer, the crease will not be so great in the case of many of the plots as ould appear from the figures given for summer and autumn in Table. In a side column of the Table is given the quantity nitrogen in lbs. per acre removed on an average per inch of ainage-water. In the three years in question the average ainage shown by the 60-inch drain-gauge amounted to 17·72 ches per annum.

The richness of the spring waters (in wet seasons), where nmonium-salts or nitrate were applied; the characteristic fferences of the summer waters, depending on the action the crop under different conditions as to the supplies of trogen and ash constituents; the increase of nitric acid in tumn on plots where nitrates had been reduced in summer; e generally similar character of the winter waters, the result of haustion by crop and drainage; and lastly, the considerable sses attending the autumn sowing of nitrogenous manures ien followed by a wet winter, are the principal facts which ll be found illustrated in the above Table.

We have already seen (pp. 102, 113) that the composition of e waters from Plots 5–10 is not strictly comparable with that the waters from Plots 11–15, the latter waters being, for some use imperfectly understood, somewhat more concentrated than e former. We may avoid this source of error if, instead of oking at the quantity of nitric acid in the different waters, we gard simply its relation to the chlorine; this is shown in able XLIX.

ABLE XLIX.—PROPORTION of NITROGEN as NITRIC ACID to 100 of CHLORINE in DRAINAGE-WATERS from BROADBALK FIELD at different SEASONS of the Year: average of THREE YEARS.

lot.	Ash constituents applied.	Spring.	Summer.	Autumn.	Winter.	Whole Year.
7	Phos. Acid, Potash, Magnesia, Soda	31·1	6·9	20·2	45·1	29·4
or 16	Ditto ditto	30·3	6·9	18·1	43·9	27·8
13	Phos. Acid, Potash ..	31·1	6·3	14·4	44·2	26·1
14	" " Magnesia	32·1	10·8	17·3	53·4	30·7
12	" " Soda ..	33·2	12·1	18·0	51·1	30·6
11	Phosphate alone	43·8	18·3	19·5	51·2	34·4
10	None	43·6	38·7	37·6	53·1	44·0

All the plots mentioned in this Table receive the same quantity both of nitrogen and chlorine, but with different supplies of ash constituents. Where the principal ash constituents required by the crop are supplied (Plots 7, 17 or 18, 13) there a large assimilation of nitrogen takes place during the summer months, and the proportion of nitrogen to chlorine in the drainage-water becomes very low. Where potash has never been applied (Plot 11), or not for many years (Plots 12, 14), a larger proportion of nitric acid escapes assimilation. Where neither phosphoric acid nor potash is applied (Plot 10), the proportion of nitric acid left untouched by the crop and removed in the drainage-water is much increased. In winter time the proportion of nitrogen to chlorine in the drainage-water is in all cases high, the chlorides of the manure having by this time been washed out of the soil to a considerable extent, while a new formation of nitric acid is continually in progress.

We must not leave the subject of the amount of nitrogen as nitrates present in the drainage-waters without referring to the quantities shown by Voelcker's and Frankland's early analyses (Table XLV.). The amount of nitrogen per million shown for the unmanured Plot 3 & 4 is identical with the average found for this plot in the later Rothamsted determinations (Table XLVII.); the amount found for Plot 5, receiving no nitrogenous manure, is also very similar to the later results; all the remaining determinations are, however, much higher than those obtained during the last three years. This difference is partly due to the extreme wetness of recent seasons, resulting in weak drainage-waters; but in the case of plots receiving ammonium-salts it is chiefly determined by the fact that, during the years to which the earlier analyses refer, the ammonium-salts were in every case applied to the land in autumn. The results obtained by Voelcker and Frankland for Plots 7, 10, 11, 12, 13, 14, 15, are thus, so far as time of sowing is concerned, comparable with those now yielded by Plot 15.

The greater loss of nitric acid in spring and summer drainage, where the ash constituents required by the crop were deficient, is equally shown by the earlier analyses (Tables XLVI. and XLVII.), as by our own later determinations.

Part IV.*—The Quantity of Nitrogen lost by Drainage.

We have now discussed in considerable detail the very numerous results obtained relating to the composition of the drainage-waters collected from the differently manured plots in

* In the 'Journal' this Part is given as Section [illegible]

the experimental wheat-field. We have shown the influence of the amount and stage of the running, the description of the manure, and the time at which it is sown, the period of the year, and the character of the seasons, on the composition of the waters.

Confining attention to the loss of nitrogen by drainage which has been indicated, it has been seen that its amount has been very directly connected with the amount supplied in the manure. The practical question obviously suggests itself— whether, in the case of the experimental wheat-field, in which known quantities of nitrogenous manure have been applied, and known quantities of nitrogen removed in the crops, for many years in succession, the facts at command are sufficient to enable us to estimate how much nitrogen has been lost by the drainage from the different plots?—and whether the whole of the nitrogen of the manure which has not been recovered in the increase of crop, may be accounted for by the ascertained loss by drainage?

It is obvious that, to be able to give an exact answer to this question, it is essential to know, not only the total amount of drainage which has passed from the land, and the amount of nitrogen it has carried with it, but also how much nitrogen has been supplied to the soil, or the crop, from the atmosphere by rain or condensation, and how much has been yielded to the crop, or to the drainage, by the soil itself?—or whether, on the other hand, some of the unrecovered amount is retained by the soil or subsoil, possibly to be slowly recovered in succeeding crops?

Unfortunately, we have no means of gauging the total amount of drainage passing from the land of the experimental wheat-field. We can only form some judgment of it from the quantities determined in the case of the 20-inch, 40-inch, and 60-inch soil-drain-gauges, the results obtained by which during between ten and eleven successive seasons have been fully described in Part II. of this Paper. It is assumed that the results of the 60-inch drain-gauge will probably afford the best basis for estimating the amount of drainage in the experimental wheat-field. It would seem probable that during the late autumn, the winter, and the early spring, the amount of drainage would not differ widely in the two cases; but that, during the active growth of the crop, and for some time afterwards, the loss would be less in the experimental wheat-field than through the drain-gauge, owing to the drying of the soil under the influence of the growing crop.

Using such data as we possess, we propose to give, in the first place, an estimate of the quantity of nitrogen lost by drainage from most of the plots of the experimental wheat-field, during two recent years, for which we have analyses of every running from the drain-pipes. We shall afterwards attempt to

total loss is given; also the excess
nitrogen in manure, over that f
manure without nitrogen. The
period is assumed to be the same
soil-drain-gauge during the same
amounts of drainage are given
The quantity of nitrogen as nitra
water for each plot is reckoned ac
analyses of the waters collected
from spring sowing to the end of
from harvest to autumn sowing,
spring sowing. For some perio
was drainage through the 60-inch
pipes in the experimental field,
composition of the drainage sho
been made. Were it not that
from the drain-pipes when there
it would be more correct to reck
the amount of drainage from the
other reasons, as will be seen furt
taken as only approximations to
sodium on Plot 9, and the am
Plot 15), were sown, in 1879 on
March 9. On Plot 15, the amm
October 15, 1878; October 22, 18

Before referring to the estimate
drainage which the Table records

Table L.—Estimated Loss of Nitrogen, as Nitrates, in the Drainage-Waters from the Experimental Wheat-Field.

Two Years. Quantities in lbs. per Acre.

Plots.		1879–80.						1880–81.						Average per Annum. 2 Years.	
		Total estimated Loss.			Loss + or − Plot 5.			Total estimated Loss.			Loss + or − Plot 5.				
		Spring Sowing to Harvest.	Harvest to next Spring Sowing.	12 Months Spring Sowing to Spring Sowing.	Spring Sowing to Harvest.	Harvest to next Spring Sowing.	12 Months Spring Sowing to Spring Sowing.	Spring Sowing to Harvest.	Harvest to next Spring Sowing.	12 Months Spring Sowing to Spring Sowing.	Spring Sowing to Harvest.	Harvest to next Spring Sowing.	12 Months Spring Sowing to Spring Sowing.	Total.	+ or − Plot 5.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3&4	Unmanured, continuously	1·74	10·82	12·56	0·18	− 2·50	− 2·32	0·58	17·13	17·71	− 0·16	− 0·60	− 0·76	14·94	− 1·74
5	Mixed Mineral Manure	1·56	13·32	14·88	..	..	..	0·74	17·73	18·47	..	..	..	16·68	..
6	Mixed Min. Man. and 200 lbs. Ammonium-salts ..	10·12	12·56	22·68	8·56	− 0·76	7·80	2·25	19·81	22·06	1·51	2·08	3·59	22·37	5·69
7	Mixed Min. Man. and 400 lbs. Ammonium-salts ..	18·31	12·63	30·94	16·75	− 0·69	16·06	4·29	21·38	25·67	3·55	3·65	7·20	28·31	11·63
8	Mixed Min. Man. and 600 lbs. Ammonium-salts ..	24·95	17·55	42·50	23·39	4·23	27·62	8·70	33·81	42·51	7·96	16·08	24·04	42·50	25·82
9a 9b	Mixed Min. Man. and 550 lbs. Nitrate Sodium .. 550 lbs. Nitrate Sodium alone	44·99	15·61	60·60	43·43	2·29	45·72	15·03	40·99	56·02	14·29	23·26	37·55	58·31	41·63
10	400 lbs. Ammonium-salts alone	42·87	14·35	57·22	41·31	1·03	42·34	7·38	35·24	42·62	6·64	17·51	24·15	49·92	33·24
11	400 lbs. Ammonium-salts and Superphosphate ..	28·29	17·75	46·04	26·73	4·43	31·16	3·37	29·57	32·94	2·63	11·84	14·47	39·49	22·81
12	400 lbs. Amm.-salts, Superphosph. and Sulph. Sodium	21·23	17·54	38·77	19·67	4·22	23·89	3·32	27·17	30·49	2·58	9·44	12·02	34·63	17·95
13	400 lbs. Amm.-salts, Superphosph. and Sulph. Potass.	19·01	16·43	35·44	17·45	3·11	20·56	3·68	25·33	29·01	2·94	7·60	10·54	32·23	15·55
14	400 lbs. Amm.-salts, Superphosph. and Sulph. Mag.	25·99	16·85	42·84	24·43	3·53	27·96	4·25	25·84	30·19	3·51	8·2	11·72	36·51	19·83
15*	400 lbs. Amm.-salts, and Mixed Mineral Manure ..	9·62	59·92	69·54	8·06	46·60	54·66	3·40	74·94	78·34	2·66	57·21	59·87	73·94	57·26
16	Unmanured, 1865 and since	1·61	12·63	14·24	0·05	− 0·69	− 0·64	0·76	17·86	18·62	0·02	0·13	0·15	16·43	− 0·25

Estimated Drainage for the same Periods.

Drainage through the 60-inch Soil-Drain-gauge – inches ..	11·1	4·7	15·8	..	..	..	1·8	18·8	20·6	..	..	..	18·2	..

* Ammonium-salts autumn sown.

therefore, during the period select
operating in opposite directions.
by drainage, the results given are e

Referring to the record of the
through the 60-inch drain-gauge du
the bottom of the Table, it will be
1879–80, there was a very large am
sowing to harvest, that is during th
of the crop, and a comparatively s
of its removal to the commencemen
ceeding spring. Accordingly we h
of nitrogen by drainage during the s
the crop than during the six or seve

In the second season, 1880–188
was a very small amount of drain
ripening of the crop, and a very exc
of its removal to the commencemen
spring. Under these very different
nitrogen lost by drainage within the
season are very different from those
scarcely any loss from spring sowin
loss from harvest to the next spring

It should be stated, however, th
1879–80 the drains only ran in Febru
in nitrates, the result of accumulation,
calculated on the composition of thos
above the truth. The losses duri

wet seasons, is strikingly shown in the results for Plot 3&4 continuously unmanured, Plot 5 receiving annually for nearly thirty years mixed mineral manure alone, but mineral and nitrogenous manure previously, and Plot 16 unmanured for sixteen or seventeen years, after excess of ammonium-salts with mixed mineral manure, previously. During the first twelve months the loss by drainage from these three plots was 12½, nearly 15, and 14¼ lbs. of nitrogen per acre; and during the second twelve months it was 17¾, 18½, and 18½ lbs. per acre. Further, notwithstanding the comparative dryness of the autumn and winter period in the first season, and the very excessive drainage during the same period of the second season, nearly the whole of the loss is, in both cases, after the removal of the crop; that is, during the long period of the year in which land under cereal culture is practically bare of vegetation. It may be here remarked, that the close approximation of the quantities estimated to be lost on Plots 5 and 16, with very similar manurial history, though the one is at one side and the other at the other side of the field, affords some evidence of the comparative character of the results in the different parts of the field.

The loss of nitrogen estimated to be derived from that of the nitrogenous manures applied, is best studied by reference to the columns in the Table which show the excess in the drainage from the plots receiving nitrogenous manure over the amount from Plot 5 with mineral without nitrogenous manure.

Comparing Plots 5, 6, 7 and 8, each receiving the same mixed mineral manure, but Plot 5 with no ammonium-salts, Plot 6 with 200 lbs., Plot 7 with 400 lbs., and Plot 8 with 600 lbs. of ammonium-salts per acre per annum, there were, during the very wet period from spring sowing to harvest in 1879, losses of 8·56, 16·75, and 23·39 lbs. of nitrogen more from the three ammonium plots than from Plot 5; that is, quantities increasing closely in proportion to the increased supply by manure. Then again, taking the series of plots with the same amount of ammonium-salts, but with different mineral manures for many years in succession, and yielding, accordingly, very different amounts of crop, there are very variable amounts of loss of nitrogen, ranging from 41·31 lbs. per acre with ammonium-salts alone (Plot 10), to only 16·75 lbs. with the same amount of ammonium-salts and the most complete mineral manure (Plot 7). The loss on the other plots of the series gradually increases with the defect of the mineral manure and the coincident defect of growth. Thus, with superphosphate of lime and potassium-salts (Plot 13) it is 17·45 lbs., or but little more than with the mixed mineral manure; with superphosphate and soda, with a residue of potash from previous applications (Plot 12), it is 19·67 lbs.; with

superphosphate and magnesia, and some residue of potash (Plot 14), it is 24·43 lbs.; with superphosphate of lime alone (Plot 11), 26·73 lbs.; and lastly, with ammonium-salts alone (Plot 10), 41·31 lbs. To such a great extent was the unused nitrogen of the manure washed out during the growth of the miserable crop on Plot 10, with the ammonium-salts alone, that there was only 1·03 lb. of that supplied accounted for in the drainage of the whole succeeding period from harvest to the next spring sowing. With this exception, the loss during the period subsequent to the removal of the crops, though very much less in actual amount, varies on the different plots much in the same order as previously.

In the dry period of growth of 1880, on the other hand, the estimated losses from the manure were comparatively small. They were as before, the greater, the greater the supply of ammonium-salts: and greater with an equal supply of them used alone than when in conjunction with mineral manure. With the excessive rain and drainage during the period of more than six months subsequent to harvest, the losses were much greater than during the period of growth; and on the plots with the same amount of ammonium-salts, but different mineral manures, the losses varied exactly in the same order as during the wet period of growth of 1879. Thus, they were on Plot 7, with the ammonium-salts and the complete mineral manure, 3·65 lbs.; on the intermediate plots, 7·60, 8·21, 9·44, 11·84; and on Plot 10, with the ammonium-salts alone, 17·51 lbs.

Finally, the average amounts of loss per acre per annum (over the two years) estimated to be due to the nitrogen of the manure, as shown in the last column of the Table, are with the same mineral manure and increasing amounts of ammonium-salts, 5·69, 11·63, and 25·82 lbs. accounted for in the drainage. And, with the same amount of ammonium-salts and different mineral manures, the average losses are—from Plot 7, with the complete mineral manure, 11·63 lbs.; from the intermediate plots, 15·55, 17·95, 19·83, 22·81; and with the ammonium-salts alone, 33·24 lbs.

Large as are these losses with the ammonium-salts spring sown, the loss is very much greater where, as on Plot 15, they were sown in the autumn, though with the same complete mineral manure as on Plot 7. The loss from the autumn-sown plot had been very great during the winter of 1878–9, and it was accordingly very much less than from the spring-sown plots during the period of growth and ripening of 1879. Receiving the ammonium-salts again in October 1879, the loss estimated to be due to the manure was 46·6 lbs. from the date of the preceding harvest to the time of spring [illegible]

n ten times as much as during the same period from plots which had not received ammonium-salts since ng spring; but it has been explained (p. 126) that nates of loss for this period are probably too high. great loss during the winter, there was very little from Plot 15 during the succeeding period of growth. receiving the ammonium-salts in October 1880, there he date of the preceding harvest to the commencement growth in the following spring, a loss of 57·2 lbs. o be due to the manure, or nearly sixteen times as om the spring-sown Plot 7 during the same period.

now to the comparison of the results on Plots 7 ot 7 received annually a given amount of nitrogen as -salts, and Plot 9 approximately the same amount as sodium. Plot 7 received also the complete mixed nure; but only one half, or one land, of Plot 9 (9*a*) e mineral manure, the other half (9*b*) receiving the odium alone. On both plots the nitrogenous manure d in the spring.

the very wet period from spring sowing to harvest was an estimated loss from the ammonium-salts of f nitrogen per acre, but from the nitrate of sodium s. There was little or no estimated loss from the either plot from harvest to the next spring sowing. g sowing to harvest (1880), with very little drainage, a loss of 3·55 lbs. from the ammonium-salts, and of from the nitrate; and during the very wet period st to the next spring sowing (1881), there was a loss of om the ammonium-salts, and of 23·26 lbs. from the sodium; or, over the whole twelve months, of 7·2 lbs. mmonium-salts, and of 37·55 lbs. from the nitrate.

vas thus a very much greater loss of nitrogen by hen a given amount was supplied as nitrate of sodium as ammonium-salts. But the loss from the nitrate ly much greater than it would have been in conse- one of the two lands receiving no mineral manure, owth on it being accordingly very much less. Still, ll generally be greater from a given amount of nitrate a corresponding quantity of ammonium-salts, when t of nitrogen supplied is much in excess of that which en up by the crop, or when the season is wet.

I. shows for the two seasons, the average annual in lbs., of nitrogen supplied in manure, obtained in estimated in the drainage, and in the crop and ogether; also the amounts unaccounted for in either inage.

TABLE LI.—NITROGEN supplied in MANURE, recovered in the CROP, and in the DRAINAGE, and unaccounted for in either Crop or DRAINAGE, in the EXPERIMENTAL WHEAT-FIELD.

TWO YEARS. QUANTITIES IN LBS. PER ACRE.

PLOTS.		Nitrogen per Acre per Annum				
		In Manure	In Crop	In Drainage	In Crop and Drainage	Un-accounted for
		lbs.	lbs.	lbs.	lbs.	lbs.
3&4	Unmanured continuously ..	0	12	15	27	(+ 27)
5	Mixed Mineral Manure ..	0	16	17	33	(+ 33)
6	Mixed Min. Man. and 200 lbs. Ammonium-salts	44	27	22	49	(+ 5)
7	Mixed Min. Man. and 400 lbs. Ammonium-salts	88	40	28	68	20
8	Mixed Min. Man. and 600 lbs. Ammonium-salts	132	49	43	92	40
9	Mixed Min. Man. (on half) and 550 lbs. Nitrate Sodium	86	32	58	90	(+ 4)
10	400 lbs. Amm.-salts, alone ..	88	14	50	64	24
11	400 lbs. Amm.-salts and Superphosphate	88	29	39	68	20
12	400 lbs. Amm.-salts, Superphos., and Sulph. Sodium	88	32	35	67	21
13	400 lbs. Amm.-salts, Superphos., and Sulph. Potass ..	88	38	32	70	18
14	400 lbs. Amm. salts, Superphos. and Sulph. Magnesium	88	37	37	74	14
15	400 lbs. Amm.-salts, and Mixed Mineral Manure ..	88	32	74	106	(+ 18)
16	Unmanured, 1855 and since	0	14	16	30	(+ 30)

In reference to the quantities of nitrogen supplied by manure, it is assumed that the 400 lbs. ammonium-salts supplied 88 lbs.; and they may have supplied nearer 90 lbs. Formerly we assumed this quantity to contain only 82 lbs.; but of late years ammonium-salts have occurred in commerce in a state of greater purity. The amount of nitrogen contributed by manure obviously by no means represents the total quantity annually available. There will be about 2 lbs. annually supplied in the seed; and there is a considerable quantity, of which we shall endeavour to form some estimate further on, annually available from the atmosphere by rain and condensation, and from the stores in the soil itself. Our present purpose is, however, only to call attention to the relation of the amount of nitrogen in the crop and drainage to that in the manure.

It will be seen that in only two cases of spring sowing of the nitrogenous manures, Plot 6 with the smallest quantity of ammonium-salts, and Plot 9 with nitrate of sodium, did the total amount in crop and drainage together, exceed the supply by manure alone.

Referring to the

and 8, with the mixed mineral manure, and 200 lbs., 400 lbs., and 600 lbs. of ammonium-salts, respectively, yielded in the crops 27 lbs., 40 lbs., and 49 lbs., and in the drainage 22 lbs., 28 lbs., and 43 lbs., of nitrogen per acre per annum. There is, therefore, notwithstanding the increased amount in the crop, the greater estimated loss by drainage the greater the excess in the manure. Still, much more remains unaccounted for in either crop or drainage the greater the amount supplied.

Compared with these results from spring sowing, we have in the case of Plot 15, with autumn sowing, considerably more nitrogen in the crop and drainage together than was supplied in the manure. In fact, with 88 lbs. supplied in the manure, it is estimated that there were 74 lbs. in the drainage alone; whilst only 28 lbs. were so accounted for on Plot 7 with the same amount of ammonium-salts not applied until the spring. Taking the amounts in crop and drainage together, there was with autumn sowing about one-fifth more, but with spring sowing about one-fifth less, accounted for than was supplied in the manure.

There was then, in these two seasons, much less of the nitrogen of the manure accounted for in crop and drainage with spring sowing than with autumn sowing; and the unaccounted-for amount was the greater, the greater the excess in the manure. We shall have to refer to this point again further on.

Such are the results of two years' direct experiment, for which we have the analysis of the drainage-waters of every running from the pipes. It has been seen that, reckoning only the nitrogen supplied in the manure against the amounts in the crop and drainage, a considerable quantity of that so supplied remains unaccounted for. We shall now endeavour to make an estimate of the average loss by drainage on the different plots, over the thirty years—1851-2 to 1880-1—during which (with a few special exceptions) the same description and amount of manure has been applied year after year on the same plot. Excepting for the crop of the second year, 1853, when the previous autumn and winter were extremely wet, the ammonium-salts were, until the last four years of the thirty, applied in the autumn; but during those four years they have not been applied until the spring. Plot 15 is the only exception to this; for the five crops—1873 to 1877 inclusive—it received the ammonium-salts in the spring; but for the last four crops—1878-1881—when all the other plots received them in the spring, Plot 15 received them in the autumn. To Plot 9, the nitrate of sodium has always been applied in the spring.

In default of more accurate knowledge of the amount of drainage from the land of the experimental wheat-field, the

drainage through the 60-inch soil-drain-gauge is in the following, as in the preceding estimates, taken as the basis of calculation. We have, however, the record of this only for the last eleven years of the thirty. For the preceding seventeen (as well as for the last eleven) years we have the record of the rainfall at Rothamsted, and for the first two years we adopt the amounts for a neighbouring station (Nash Mills); so that thus we have the rainfall for the first nineteen years. Then, each year being divided into the characteristic periods—from autumn sowing to spring sowing, from spring sowing to the end of May, from June 1 to harvest, and from harvest to autumn sowing again—the rainfall for each such period for each of the first nineteen years is taken; and the drainage of each period is assumed to be the same as with the nearest corresponding rainfall for like periods during the eleven years for which the record of both rainfall and drainage is available.

As to the composition of the drainage, the amounts of which are so estimated, we have for the twenty-five years during which the ammonium-salts were sown in the autumn, only the few determinations by Dr. Voelcker and Dr. Frankland, on samples collected in only a few of the twenty-five years. Upon these we have to rely in estimating the composition of the drainage of two of the most important of the four periods of the year into which each of the twenty-five years is divided; and for the other periods, less influenced by the time of sowing the manure, or by growth, average figures are adopted from the more recent determinations. For the second year of the thirty, when the ammonium-salts were spring-sown, and for the first of the last four years of spring sowing, the composition of the drainage of the different periods of the season is calculated according to the average results for the corresponding periods of the last, or succeeding three years. For these three years themselves, an almost complete series of actual determinations is available.

The following Table (LII.) gives the so estimated losses of nitrogen by drainage, in lbs. per acre per annum, for each of the different series of years. It also gives the average for the whole thirty years; and for comparison the mean for the two years from the time of spring sowing in 1879 to the same period in 1881. In the last two columns are given, for the thirty years, and for the two years, the estimated losses from each plot receiving nitrogenous manure over Plot 5 with mineral manure alone.

With regard to these estimates for different series of years, we will only call attention to the fact that they differ from one another in the direction that it would be expected they would

ABLE LII.—ESTIMATED LOSS of NITROGEN, as NITRATES, in the collected DRAINAGE-WATERS from the different PLOTS in the EXPERIMENTAL WHEAT FIELD.

THIRTY YEARS, QUANTITIES IN LBS. PER ACRE.

LOTS.	19 years, 1851–2, to 1869–70.	7 years, 1870–1, to 1876–7.	1 year, 1877–8.	3 years, 1878–9. to 1880–1.	30 years, 1851–2, to 1880–1.	2 years, 1879–80, to 1880–1.	+ or – Plot 5. 30 years, 1851–2, to 1880–1.	+ or – Plot 5. 2 years, 1879–80, to 1880–1.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3 & 4	9·1	11·1	11·8	15·9	10·3	15·2	– 1·7	– 1·5
5	10·6	13·2	13·6	17·3	12·0	16·7	..	..
6	17·3	22·7	20·9	20·7	19·0	22·4	+ 7·0	+ 5·7
7	28·9	38·9	31·6	25·8	31·0	28·3	+ 19·0	+ 11·6
8	39·9	53·2	40·5	34·3	42·5	42·5	+ 30·5	+ 25·8
9	32·5	35·6	60·3	48·0	35·7	58·3	+ 23·7	+ 41·6
10	40·4	49·4	48·2	44·8	43·2	49·9	+ 31·2	+ 33·2
11	38·1	49·6	38·5	35·2	40·5	39·5	+ 28·5	+ 22·8
12	34·3	45·7	34·2	30·1	36·5	34·6	+ 24·5	+ 17·9
13	35·4	48·2	35·9	27·7	37·6	32·2	+ 25·6	+ 15·5
14	36·9	49·4	42·0	32·1	39·5	36·5	+ 27·5	+ 19·8
15	34·3	*23·3	58·9	63·5	35·5	74·0	+ 23·5	+ 57·3
16	11.9	14·7	14·8	16·6	13·1	16·4	+ 1·1	– 0·3

* Five years spring-sown.

lo, having regard to the difference in the characters of the easons, to the average character of the crops accordingly, and o the time of year at which the ammonium-salts were sown.

The next Table (LIII.) shows for the whole thirty years: in the upper division, the estimated amounts of nitrogen removed in the crops and lost in the collected drainage, also the amount of that supplied which is unaccounted for in either crop or drainage; in the middle division, the excess of the amounts on he plots with nitrogenous manure over those on Plot 5 without t, and the amounts of that supplied in manure which are not ccounted for in the increase in crop and drainage together. inally, there is given the percentage on the amounts supplied n manure, recovered in the *increase* in crop, in the *increase* in rainage, and unaccounted for in either.

The first four columns show the results for Plot 5 with the ineral manure alone, Plot 6 with the mineral manure and 00 lbs. ammonium-salts, Plot 7 with the mineral manure and 00 lbs., and Plot 8 with the mineral manure and 600 lbs. mmonium-salts. It is seen that the nitrogen in the crop ncreases considerably, and that in the drainage increases proortionally more, with each increase of nitrogen in the manure. ut if the amounts in the produce and drainage without amnonium-salts (Plot 5) be deducted from those with ammonium-

TABLE LIII.—Estimated NITROGEN supplied in MANURE, recovered in the CROPS and in the collected DRAINAGE, and unaccounted for in either CROP or DRAINAGE, in the EXPERIMENTAL WHEAT FIELD.

THIRTY YEARS, 1851-2 to 1880-1, inclusive.

	Mixed Mineral Manure.				86 lbs. Nitrogen per Acre per Annum in Manure.						
		Ammonium-salts equal to			As Ammonium-salts.						As Nitrate.
	Without Ammonium-salts. PLOT 5.	43 lbs. Nitrogen. PLOT 6.	86 lbs. Nitrogen. PLOT 7.	129 lbs. Nitrogen. PLOT 8.	Without Mineral Manure. PLOT 10.	Super-phosphate. PLOT 11.	Super-phosphate and Soda. PLOT 12.	Super-phosphate and Potass. PLOT 13.	Super-phosphate and Magnesia. PLOT 14.	Mixed Mineral Manure. PLOT 7.	Mixed Mineral Manure (on half). PLOT 9.
TOTAL.											
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Nitrogen: In Crop	20·3	32·8	46·2	57·4	32·7	38·0	42·5	43·7	44·4	46·2	46·3
Nitrogen: In Drainage	12·0	19·0	31·0	42·4	43·2	40·5	36·5	37·6	39·5	31·0	35·7
Total	32·3	51·8	77·2	99·8	75·9	78·5	79·0	81·3	83·9	77·2	82·5
Unaccounted for ..	..	+ 8·8	8·8	29·2	10·1	7·5	7·0	4·7	2·1	8·8	3·5
EXCESS over PLOT 5.											
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Nitrogen: In Crop	..	12·5	25·9	37·1	12·4	17·7	22·2	23·4	24·1	25·9	26·5
Nitrogen: In Drainage ..	..	7·0	19·0	30·4	31·2	28·5	24·5	25·6	27·5	19·0	23·7
Total	..	19·5	44·9	67·5	43·6	46·2	46·7	49·0	51·6	44·9	50·2
Unaccounted for ..	..	23·5	41·1	61·5	42·4	39·8	39·3	37·0	34·4	41·1	35·8
EXCESS over PLOT 5. Per Cent. (SUPPLIED by MANURE equal 100.)											
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Nitrogen: In Crop	..	29·1	30·1	28·8	14·4	20·6	25·8	27·2	28·0	30·1	30·8
Nitrogen: In Drainage ..	..	16·3	22·1	23·6	36·3	33·1	28·5	29·8	32·0	22·1	27·6

ıere is, so reckoned, a very large and increasing amount supplied unaccounted for in either crop or drainage.

next six columns of the Table show the amounts of n in the crop, and estimated in the drainage, on six each receiving 86 lbs. of nitrogen annually as ammoalts, in one case without any mineral manure, and others with different descriptions of mineral manure, whole period of 30 years or more. The amount of n annually removed in the crop is 32·7 lbs. with the ium-salts alone, and gradually increases with the adof the different mineral manures until it reaches 46·2 lbs. he ammonium-salts and the most complete mineral . The estimated amount in the drainage, on the other s the highest, 43·2 lbs., with the ammonium-salts alone, e lowest with the ammonium-salts and the complete l manure, namely, 31·0 lbs. The amounts in the crop ainage respectively, are indeed, in the two cases, to a xtent complementary. Thus, with the ammonium-salts here are, in crop and drainage together, 75·9 lbs., made 32·7 lbs. in crop, and 43·2 lbs. in the drainage; and, e ammonium-salts and mixed mineral manure, there are and drainage 77·2 lbs., but made up of 46·2 lbs. in the nd of 31 lbs. in the drainage. The intermediate plots ow upon the whole the less in the drainage the more in the crop.

general result is that with the same amount of amn-salts and the complete mineral manure, there is ximum amount of nitrogen per acre in the crop and nimum amount in the drainage; but with the amn-salts without mineral manure, there is the minimum in the crop and the maximum amount in the drainage. with the six very different conditions as to mineral , there is upon the whole the less accounted for in crop inage together, the less the amount in the crop, and the the actual amount in the collected drainage. There is as before, though more in the drainage, more entirely inted for the greater the excess over the demands of the whilst, with the more favourable conditions of growth in to mineral supply, and the more nitrogen taken up in p, the total amount in crop and drainage the more nearly imates to the amount annually supplied in manure. is some exception to this; but there is reason to believe e drainage results for that plot are somewhat too low, haps those of Plot 14 rather too high. Indeed, the total in crop and drainage is less for Plot 7 with ammonium- most years sown in the autumn) and the mixed mineral

manure, than for Plot 9 with nitrate of sodium (always sown in the spring) and the mixed mineral manure on one-half only of the plot. With these differences there is on Plot 9 even rather more recovered in the crop, and there is more also in the drainage

Finally, in these estimates for the thirty years, with much better average seasons, and much more nitrogen recovered in the crops, but with mostly autumn sowing, and generally rather more nitrogen in the drainage from the ammonia-plots, there is considerably more accounted for in crop and drainage together, than over the two seasons of spring sowing, and excessive drainage. The estimated amounts in the drainage were, indeed, over the two years, greater, or about equal, with defective mineral supply and defective growth accordingly, but they were less under the more favourable conditions of growth than over the thirty years.

It will be seen that in the foregoing comparisons of the amounts of nitrogen in the total crop and drainage with the amounts supplied in manure, no account is taken of the small quantity (say 2 lbs. per acre per annum) supplied in the seed, and the very much larger quantity contributed by rain and condensation from the atmosphere, and by the soil itself; nor of how much, if any, is retained by the soil.

Assuming that the crop and drainage of the plots receiving nitrogen in manure have received the same amount from other sources as Plot 5 without such manure, the amounts in the crop and drainage respectively, of that plot, have been deducted from the amounts for the other plots, and the result is given in the middle division of the Table. The amounts so deducted are, for crop 20·3 lbs., for drainage 12 lbs., together 32·3 lbs. Reckoned in this way, a very large amount of the nitrogen supplied by manure appears unaccounted for in crop and drainage. The quantities so unaccounted for amount, as shown in the bottom line of the Table, to from 40 to 50 per cent. of the total amount supplied; and with 86 lbs. of nitrogen in manure they range from 34·4 lbs. to 42·4 lbs. per acre per annum. The figures further show that, with the best conditions of mineral manuring and of growth, 30·1 per cent., or less than one-third of the supplied nitrogen, is recovered in the *increase* of crop, and that 22·1 per cent. have appeared in the drainage. Compared with this result there is, with the 400 lbs. of ammonium-salts alone, only 14·4 per cent. reckoned to be recovered in the increase of crop, and 36·3 per cent. found in the drainage. The results for the plots with the partial mineral manures are intermediate between these two extremes.

The next question is ... whether ...

the nitrogen of manure within the soil which may account for some or all of the large amount otherwise unaccounted for? In 1865 careful samples of the soil were taken from eleven of the differently-manured plots in the Experimental Wheat-field. The samples were taken from eight places on each plot, and in each case to three depths of 9 inches, or in all to a depth of 27 inches: and the eight samples of the same depth were mixed together. In no case were less than three determinations of nitrogen made in these mixed samples, and in some four or more. The following Table (LIV.) shows the mean percentage of nitrogen in the dry mould (that is, excluding stones and moisture) in the mixed samples of the first 9 inches of depth for each of the eleven plots. It also shows the calculated amounts of nitrogen per acre (reckoning 2,300,000 lbs. of dry mould to the depth of 9 inches), and the amounts on the other plots more or less than on Plot 5.

TABLE LIV.—MEAN PERCENTAGE, and QUANTITY PER ACRE, of NITROGEN in the SURFACE SOIL (9 inches deep) of SELECTED PLOTS in the EXPERIMENTAL WHEAT FIELD.

SAMPLES COLLECTED OCTOBER 1865.

PLOTS.	Manures per Acre per Annum.	Nitrogen in Dry Mould.		
		Per Cent.	Per Acre.	Per Acre, + or − Plot 5.
		Per cent.	lbs.	lbs.
2	14 tons Farm-yard Manure	0·1882	4329	+ 1755
3	Unmanured	0·1090	2507	− 67
5a	Mixed Mineral Manure	0·1119	2574	..
7a	Mixed Min. Manure and 400 lbs. Amm.-salts ..	0·1230	2829	+ 255
9a	Mixed Min. Man. and 550 lbs. Nitrate of Sodium	0·1232	2834	+ 260
10a	400 lbs. Amm.-salts, alone (1845 and since) ..	0·1108	2548	− 26
11a	400 lbs. Amm.-salts and Superphosphate ..	0·1171	2693	+ 119
12a	400 lbs. Amm.-salts, Superphos. and Sulph. Soda.	0·1208	2778	+ 204
13a	400 lbs. Am.-salts, Superphos. and Sulph. Potass.	0·1206	2774	+ 200
14a	400 lbs. Amm.-salts, Superphos. and Sulph. Mag.	0·1197	2753	+ 179
16a	800 lbs.* Amm.-salts and Mixed Min. Manure	0·1264	2907	+ 333

These determinations of nitrogen relate to the condition of the plots after all had been under experiment for 22 years in succession. The unmanured and the farmyard-manured plots had been subject to the same treatment from the commencement. Each of the other plots had, respectively, received the same description, and with immaterial exceptions the same amount, of manure for the last 14 years of the 22, but had been somewhat differently manured during the first 8 years.

* To 1864 inclusive, but none in 1865, or since.

Confining attention for the present to the several artificially-manured plots, it is seen at a glance that, with the exception of Plot 10, with the ammonium-salts alone, all the plots receiving annually 400 lbs. of ammonium-salts show a higher percentage and actual amount of nitrogen in the surface-soil than Plot 5 with the mineral manure without ammonium-salts; and Plot 16, which, during the first 13 of the 14 years had received annually 800 lbs. of ammonium-salts, or twice as much as any of the others (but had since grown one crop without any ammonia) shows a higher amount still. Without claiming absolute accuracy for the figures, it cannot fail to be observed that the excess on the different plots over Plot 5, as given in the last column of the Table, is very closely in the order of the amounts of nitrogen in the crops, and almost the converse of the order of the amounts in the drainage, as shown in Table LIII. Thus, there are the highest amounts in the crop, and the highest amounts in the surface-soil, on Plots 7*a* and 9*a*, with the most complete mineral manure; and the estimated loss by drainage from those plots is the lowest. There are less amounts of nitrogen in the crops, less in the soil, and there is more estimated loss by drainage, on Plots 12, 13, and 14, with superphosphate, and either soda, potash, or magnesia. There is less still in the crop, less still in the soil, and more loss in the drainage, on Plot 11, with only superphosphate as mineral manure. Finally, there is the least in the crop, no excess in the soil, and the most in the drainage, of Plot 10, with the ammonium-salts alone.

The second and third 9 inches of soil also show in most cases some, but a variable amount of excess of nitrogen in the case of plots receiving nitrogenous manure; but it would lead to too long a discussion to consider the results in any detail. This must be reserved for a special Report on our very numerous determinations of nitrogen in soils.

It may be stated, however, that in the autumn of last year (1881) samples were again taken, to three depths of 9 inches each, or to a total depth of 27 inches, from 20 plots in the Experimental Wheat-field, and the determination of nitrogen in them is now in progress. With regard to the results, we can only now state the significant fact that, so far as the amount of nitrogen in the surface-soil is concerned, the relation of plot to plot is essentially accordant at the two periods. Thus, the determinations in 1865 were made after 14 years, and those of 1881 after 30 years of continuous experiment; the amount of nitrogen in the surface-soil of Plot 5 without ammonium-salt is lower in 1881 than in 1865; and the difference in the amount on the different ammonium plots, compared with Plot 5, is, in most

cases, approximately, twice as great after the 30 as after the 14 years. The order of excess of nitrogen on the different plots is again, in 1881, almost parallel with that of the increased yield of nitrogen in the crops, and it is almost the converse to that of the amount estimated to be lost by drainage.

From these facts it is obviously to be concluded that the relative excess of nitrogen in the soil of the different plots receiving nitrogen in manure, is much more closely connected with the amount of growth, than with direct retention of the nitrogen of the manure. In other words, the difference is mainly due to the residue of the crops—to the stubble and roots, and perhaps to weeds.

Further, the excess on the ammonia plots compared with Plot 5, is much more due to the reduction in the nitrogen of Plot 5 than to any increase on the ammonia plots; for the percentage in these is very nearly the same at the two periods, being, as a rule, slightly higher in 1881 than in 1865 on the plots of the best growth, and slightly lower on those of deficient growth. The indication is, therefore, not that the ammonia-plots have gained in the degree which the excess in the amounts over Plot 5 would show; but only that the loss which the soil itself has sustained in all cases, has been more or less completely compensated by the retention of nitrogenous crop residue, which has taken place much in proportion to the amount of crop grown and removed.

It is obvious that we must suppose a certain amount of nitrogen has been supplied to the crop, or to the drainage, or to both, from the soil itself. Whether this amount is greater or less where there is a liberal supply of nitrogen by manure than where there is not, the data do not enable us to determine with any certainty. On this point it may be stated that, taking the average of the whole 30 years, the estimates show an annual yield of nitrogen on the unmanured plot of 18·6 lbs. in the crop, and 10·3 lbs. in the drainage, or in all 28·9 lbs. per acre per annum. In like manner Plot 5, receiving nitrogenous manure during the first 8 years, but mineral manure only during the last 30 years, has yielded 20·3 lbs. in the crop, and 12 lbs. in the drainage, or in all 32·3 lbs. per acre per annum. So far as can be estimated, it would appear that the soil of each of these two plots has on the average of 30 years lost about two-thirds of these amounts annually, to the depth of 27 inches. There would remain, therefore, about one-third—say 10 lbs., more or less—to be contributed by seed, and by rain and condensation from the atmosphere. Of this about 2 lbs. will be due to seed, leaving not much more to be otherwise accounted

for than has been shown to be annually supplied in rain and the minor deposits from the atmosphere.

Assuming 32 lbs. of nitrogen to be annually contributed by seed, rain and condensation, and the soil, to the vegetation and the drainage of the plots receiving nitrogen in manure, there is, as has been shown, a considerable amount of the total nitrogen available, which is not accounted for in the crop and drainage. Deducting the amounts in crop and drainage of Plot 5 from those of the other plots, as in Table LIII., it was shown that with 86 lbs. of nitrogen supplied in 400 lbs. ammonium-salts, there remained from 34 to 42 lbs. unaccounted for in increase of crop and drainage. Or, if we add the 32 lbs. assumed to be available from other sources to the 86 from the ammonium-salts, we have 118 lbs. annually available from all sources; and, as we have under the most favourable conditions of mineral supply and growth only about 80 lbs. in total crop and collected drainage, there remain, on this mode of reckoning, about 38 lbs. of the 118 annually unaccounted for; and with excess of nitrogen in manure very much more.

As on these modes of reckoning, the same amount is assumed to be available from seed, atmosphere, and soil, as to Plot 5, it is clear that the amount in the soil of the different plots in excess of that on Plot 5, is to be reckoned as so much reduction of the amount otherwise unaccounted for. So far as can be judged from the results already at command, it would appear that, with 86 lbs. of nitrogen supplied in manure, and the more favourable conditions of mineral supply and growth, perhaps one-third of the deficiency will be accounted for in the soil. There would still remain, therefore, say 25 lbs., more or less, annually unaccounted for, and the amount will be the greater the more defective the conditions of growth, or the greater the excess in manure. The latter are, nevertheless, the conditions under which the collected drainage accounts for the greatest actual quantity.

Either then the amounts of nitrogen estimated to be lost by drainage are too low, or there is some other source of loss.

With regard to the first supposition, it is admitted that there is uncertainty in the estimates of the total amount of drainage passing from the land; that it is a question how far the composition of the drainage collected from the pipes represents that of the total drainage; and that at any rate the determinations of nitric acid in the drainage-waters are but few, indeed far too few, for the long series of years during which the nitrogenous manures were sown in the autumn. On this point it may be observed that in the case of the two years of unusually frequent drainage, and when every flow from the pipes was analysed, the amounts of nitrogen estimated to be lost by drainage from the

autumn-sown Plot 15 was, together with the amount in the crop, nearly sufficient to account for the whole estimated to be available within that period; and so far as can be judged, the accumulation of residue within the soil would fully make up the deficiency. It must be borne in mind, however, that that period was very circumscribed.

It is obvious that in the case of the Experimental Wheat-field, with not many feet of clay sub-soil, and chalk below, favouring natural drainage, there will be much drainage from the land when none flows from the pipes. In fact, none does flow from the pipes except under the influence of continuous or heavy rain. The character of the drainage collected from them will, therefore, depend very directly on the contents of the soil above their level. Now, reference to the details of the analyses shows that the drainage-waters contained rather less chlorine at the end than at the beginning of the two years for which the loss of nitrogen by nitrates in the collected drainage-waters has been estimated. It is concluded, therefore, that none of the chlorine which had been supplied by manure and rain within the period, still remained above the level of the drain-pipes. But when the quantity of chlorine in the collected drainage-waters is calculated in the same way as the loss of nitrates has been estimated, it is found that in most cases a considerable amount of the chlorine supplied, and not appropriated by the crop, remains unaccounted for. Further, comparing the results for Plots 6, 7, and 8, with increasing amounts of chlorine supplied in the manure, the quantity unaccounted for is the greater, the greater the amount supplied. Thus, in the case of the chlorine, which is supplied in a condition at once highly soluble and diffusible, and the distribution of which will be less influenced by vegetation than will that of the nitrates, there is a considerable amount unaccounted for in the crop and the collected drainage, and there is evidence indicating that it does not remain above the level of the drain-pipes. The conclusion is that it has passed downwards by diffusion, and by drainage other than through the pipes. Calculation leads to the conclusion that nitrates have disappeared in the same way.

In the case of autumn sowing, the manure is on the ground four or five months before the commencement of vegetation, and during a period when there will usually be much more frequent drainage from the pipes than subsequently. It is to be supposed that under such circumstances a larger proportion of the nitrates which are formed near the surface will get directly into the pipes than under the average conditions with spring sowing; and so far as this is so, there will be less disappearance

equalled that recovered in the increase of crop, whilst in unfavourable conditions it considerably exceeded it. Further, there can be no doubt that the actual loss by drainage was greater than the reckonings showed. These results are of very great importance as illustrations of the loss which may occur under known conditions.

The average conditions of practical agriculture are, however, not such as to lead to the loss by drainage of so large a proportion of the nitrogen supplied by manure. When ammoniacal manure or nitrate is used, it will generally be in less quantities than in the experimental wheat-field, in which so much loss by drainage has taken place; and such manures should only be applied when there is a growing crop ready to utilise them. But by far the greater part of the nitrogen supplied to the soil in ordinary agriculture is in farmyard-manure, or is directly deposited by animals. In either case a comparatively small proportion of the nitrogen becomes immediately soluble within the soil, and there will, therefore, be the less liability to loss by drainage. If the soil be heavily manured, and rich in organic matter, and especially if it be water-logged, and not freely aërated, there will be more danger of loss by the evolution of free nitrogen. Further, a considerable amount of the nitrogen of farmyard-manure will be ineffective, because it remains insoluble, and, so to speak, dormant within the soil. Again, in ordinary agriculture, a great variety of plants is grown in alternation one with another. The ground is thus covered with vegetation for longer, and at different, periods of the year, than in the case of a continuous cereal crop; whilst the various plants will have various root-ranges and habits of growth. Hence the nitrates brought into solution are in a much greater degree arrested by the growing crops. It has been shown in the case of the two wet seasons, the full details respecting which have been given, that during the autumn and winter, when there was no crop on the ground, there was even from the plots receiving no nitrogen in manure, a loss by drainage of from 15 to 20 lbs. of nitrogen per acre per annum; whilst from the plots highly manured with ammonium-salts or nitrate, the losses during the same period were very much greater. How great may be the loss by drainage with a bare fallow in wet seasons has been fully illustrated by the results relating to the drainage collected from the soil-drain-gauges, and the fact is here again strikingly brought to view.

SUMMARY.

Amount and Composition of Rainfall.

HE rainfall at Rothamsted during 28 years, 1853–80, has d from 18·56 inches in 1864 to 36·04 inches in 1879, the ge being 28·30 inches.

Determinations of ammonia at Rothamsted in the rain of –4 showed an average of 0·74 nitrogen per million; determinations by Way (1855 and 1856) 0·88 and 1·18 nitrogen per on. Frankland's determinations in 1869–70 showed 0·37 per on. Determinations made quite recently at Rothamsted rm Frankland's results; the earlier figures are probably igh.

The total nitrogen supplied in the annual rainfall at amsted is probably 4 to 5 lbs. per acre, excluding the contion by the soil. The mean of continental estimates, ding localities near towns, is 10·23 lbs. per acre.

The chlorine in Rothamsted rain has averaged 13·42 lbs., l to 22·12 lbs. pure common salt per acre per annum. At icester the amount is equal to 53·66 lbs. of salt.

INAGE-WATERS FROM LAND UNMANURED AND UNCROPPED.

The annual drainage during 10 years, 1870–1 to 1879–80, three drain-gauges, of heavy loam with clay subsoil in ral condition of consolidation, 20, 40 and 60 inches deep, varied from 4·97 to 25·86 inches, mean 13·49 inches, or , 60·5, and 43·4 per cent. of the rainfall.

The evaporation from the bare soil averaged 5·58 inches October to March, and 11·97 inches from April to Sepier, total 17·55 inches. The evaporation during the sumand whole year is a fairly constant quantity with great rences of rainfall.

The evaporation from a cropped soil is far more considerand very variable.

Nitrates are largely produced in soil by the action of a g ferment on the nitrogenous organic matter and amia; nitrification takes place chiefly in the upper layer of soil, is greatly favoured by the presence of water, and by summer erature. The waters from the drain-gauges are richest in tes in late summer and autumn, and poorest in spring.

The quantity of nitrogen as nitrates annually removed in drainage-waters (October to September) has varied from 3 lbs. to 57·95 lbs. per acre; the average of four years,

1877–8 to 1880–1, is 41·81 lbs., equal to 268 lbs. of ordinary nitrate of sodium per acre.

10. The amount of chlorine in the drainage from the drain-gauges is approximately the same as in the rainfall.

11. The advantage of a bare fallow is largely due to the production of nitrates in the soil; in fields in bare fallow at Rothamsted 50 lbs. per acre of nitrogen as nitrates have been found at the end of summer in the first 20 inches. If followed by a wet winter, bare fallow must result in a serious loss of soil nitrogen.

Drainage-waters from Land Manured and Cropped with Wheat.

12. The drainage-water passing through a natural soil is of two kinds:—1. Surface-water passing downwards through open channels. 2. The discharge from the saturated soil. The first is much weaker than the second, save when soluble manures have been recently applied to the surface.

13. The annual average loss of lime and magnesia by drainage from the continuously unmanured wheat-plot is apparently about 223 lbs.; where 400 lbs. ammonium-salts are applied, the loss is 389 lbs.; where sulphates of sodium, potassium, and magnesium are also added, the loss is still greater; the two last-named salts exerting most influence. Nitrate of sodium does not apparently increase the loss of lime.

14. The chlorine and soda applied in manure are retained to only a small extent, either by the wheat-crop or the soil; sulphuric acid is retained to a somewhat greater extent. Phosphoric acid and potash are very perfectly retained, the part unassimilated by the crop being held by the soil, chiefly in the upper layers; this is especially true of phosphoric acid.

15. The quantity of nitric acid lost by drainage from unmanured land cropped with wheat, is far smaller than that lost by uncropped land, the crop assimilating the nitrates formed. In summer the drainage-waters contain little or no nitrates; after harvest nitrates reappear, and are found in the waters through the winter.

16. When ammonium-salts are applied to land, the ammonia is at first retained by the soil, while the sulphuric acid or chlorine passes into the drainage-water, chiefly as calcium salts.

17. The conversion of the ammonia into nitric acid commences almost immediately after the application of ammonium-salts to wet soil, the conversion is apparently complete in a few weeks if wet weather follows. The nitrogen of rape-cake is more slowly converted into nitric acid.

18. The drainage-waters from plots manured with ammonium-.lts are richest in nitrates shortly after their application. With)0 lbs. of ammonium-salts per acre applied in March, the April rainage-waters have averaged 6·7 lbs. of nitrogen (= 42·8 lbs. itrate of sodium) per inch of drainage.

19. With an equivalent amount of nitrogen applied at the ıme time as nitrate of sodium, the April drainage-waters have ›ntained 11·8 lbs. of nitrogen (= 75·6 lbs. nitrate of sodium) ɜr inch of drainage.

20. In summer the drainage-waters from plots receiving)0–400 lbs. ammonium-salts contain little or no nitrates if ıosphates and potash have been supplied; but with an excess ammonia, or a deficiency of ash-constituents, the nitrates roduced are imperfectly assimilated by the crop, and appear ı the drainage-water.

21. In winter time the drainage-waters from all the plots tend approximate in composition.

Quantity of Nitrogen Lost per Acre by Drainage.

22. Taking the average of two seasons of excessive drainage, ıt for which we have analyses of every running from the drain-.pes in the Experimental Wheat-field, it was estimated that om 15 to 17 lbs. of nitrogen were lost per acre per annum by ·ainage from plots which had received no nitrogenous manure r many years. Nearly the whole of this loss occurred during .e period of the year when there was either no crop on the ·ound, or but little growth.

23. With 44, 88, and 132 lbs. nitrogen applied as ammonium-lts in the spring, the estimated loss by drainage was 22, 28, ıd 42 lbs. of nitrogen per acre per annum. With 88 lbs. of .trogen applied as ammonium-salts, without or with different ineral manures, the loss ranged from 28 lbs. with the most beral mineral manure, to 50 lbs. without any mineral manure r many years. The loss was the greater, the greater the ›ficiency of available potash and phosphoric acid in the soil. ʳith nitrate of sodium, spring sown, the loss was greater than ith ammonium-salts; but it was greater still with ammonium-lts, autumn sown.

24. Reckoned over thirty years, with much better average asons, the estimated loss by drainage was from 10 to 12 lbs. nitrogen per acre per annum, without any nitrogenous anure. With 43, 86, and 129 lbs. nitrogen applied as ammo-um-salts, in most years autumn sown, the estimated loss was), 31, and 42·4 lbs.; and with 86 lbs. nitrogen applied, with-:t, or with different mineral manures, the estimated loss ranged

..covered in the crop, and
but with the ammonium-s
amount in the crop, and th

27. Only with the small
the amount of nitrogen in
more than was supplied in
was a greater or less defici
in manure (which was not
drainage), it is estimated th
be contributed per acre p
and condensation of combi
perhaps more by the soil in

28. Analyses of the soils
ferent periods, show that th
ably reduced where no nitr
where nitrogenous manures w
stationary, or slightly incre
the condition of the soil as
amount of growth. In fact,
nitrogen in the soils of the
pared with that where none
to the amount of growth, an
the crops.

29. The amount of nitrog
be lost in the drainage, tog
where it was supplied in m
for the whole of that so ...

would be very little loss from either of these sources, and that the loss is almost exclusively by drainage.

31. In ordinary agriculture, with a larger proportion of the nitrogen supplied in farmyard-manure or animal-manures, with ammonia or nitrate used in smaller quantities, and with a variety of crops covering the ground with vegetation for longer periods of the year, the loss of nitrogen per acre by drainage will be considerably less than it has been shown to be in the Experimental Wheat-field.

Practical Conclusions.

1. Most of the nitrogen of farm-crops is derived from the nitric acid of nitrates within the soil.

2. The nitric acid in the soil is produced from the nitrogenous compounds of the soil itself, from the nitrogenous organic matter of animal and vegetable-manures, from the ammonia of artificial-manures, and from the ammonia supplied by rain and condensation from the atmosphere. A very small quantity of ready-formed nitric acid is supplied by rain and condensation from the atmosphere. Nitric acid is also provided by the direct application of nitrates.

3. The ammonia of ammonium-salts is rapidly converted into nitric acid in the soil, as also is the nitrogen of some organic matters, such as urine. The nitrogen of rape-cake, that of the less soluble parts of farmyard-manure, of stubble, of roots, &c., is much more gradually converted into nitric acid, and it may require many years for the conversion of the whole of it. The nitrogenous compounds of the soil itself are very slowly converted into nitric acid, but the soil yields a certain quantity every year.

4. When there is no vegetation, and there is drainage from the land, or even when there is vegetation, and excess of drainage, nitric acid is lost by drainage.

5. As in the case of permanent grass-land the soil is always covered with vegetation, there will be with it the maximum amount of nitric acid utilised by the crop, and the minimum amount lost by drainage. Land without vegetation will be subject to the maximum loss of nitric acid by drainage.

6. The power of a growing crop to utilise the nitric acid in the soil is much diminished if there be a deficiency of available mineral constituents, and especially of potash and phosphoric acid, within the reach of the roots.

7. As the various crops grown upon a farm differ very much as to the period of the year of their most active growth, the length of time they remain on the land, and the character and

10. When oilcakes or o
the formation of nitric acid
but continues longer than
When there is a liberal use
of nitrogenous and mineral
such accumulation is know
Under such circumstances th
or it may even be considerab.

APPENDIX TABLES I., II., AND III.

EXPLANATION.

Tables give the determinations of Nitrogen as Nitrates, and of ›rine (also Nitrogen to 100 Chlorine) in all the samples of aage-water from the Experimental Wheat-field at Rothamsted :h have been analysed—about 1500 in number The results are nged in the chronological order of the collections, which range ı December 1866 to March 1882.

TABLE I., p. 153, gives the determinations made by Dr. Voelcker and Dr. Frankland.

TABLE II., pp. 154–159 inclusive, gives the determinations made at Rothamsted.

TABLE III., pp. 160–167, gives the determinations made at Rothamsted, in samples taken successively from the same runnings, of selected plots, on numerous occasions.

t the head of each column is given the date, and generally the , of collection; also the rainfall measured at 9 A.M. on the day llection, or on the preceding or succeeding days, as the case may :hus indicating, in some degree, the relation of the running of rains to the proximate rainfall, or to the previous condition of oil as to moisture, and giving the means of judging whether ollection is during, or only subsequent to, the rainfall. The al character of the running is further indicated by the words bling," "small," "moderate," "half full," "continued," &c. e 0·0 is entered in a column, the sample was examined, but ined none of the constituent; where n. r. is entered, there was nning from that plot; where n. a. is entered, there was running, o analysis of the water.

here the vertical lines between columns are doubled, the nitroas manures were sown between the dates of the two collections parated, and the exact date of the application is given in the notes

entered in the foot-notes.

If the quantity of Nitroge
water be multiplied by ·226 (
represent the amount of loss p
that strength. Thus, the first
as Nitric Acid, per million dra
4·43 lbs. Nitrogen lost per ac

…DBALK EXPERIMENTAL WHEAT-FIELD, ROTHAMSTED.

…FRANKLAND.

PLOTS.	1872 ([4]).				1873 ([5]).		PLOTS.
	…6. Rain: 9 A.M. …an 4 „ 5 „ 6. …rate. …land)	May 18. Rain: 9 A.M. 0·01 May 17. 0·69 „ 18. Small (Frankland).	June 11. Rain: 9 A.M. 0·34 June 9. 0·39 „ 10. 0·41 „ 11. Small. (Frankland)	Oct. 26. Rain: 9 A.M. 0·34 Oct. 24. 0·56 „ 25. 0·36 „ 26. Moderate. (Frankland).	Jan. 19. Rain: 9 A.M. 0·01 Jan. 18. 0·73 „ 19. 0·16 „ 20. Moderate. (Frankland.	Feb. 26. Rain: 9 A.M. 0·84 Feb. 26. 0·07 „ 27. Small. (Frankland).	
2	…Jan. 6,	n. r	n. r.	9·3	0·8	0·8	2
3 & 4	·1	0·3	0·0	3·7	0·6	1·3	3 & 4
5	·2	0·7	0·0	3·6	1·6	0·9	5
6	·8	0·6	0·0	13·5	4·5	1·2	6
7	·4	0·6	0·0	23·0	12·9	4·8	7
8	·4	0·9	n. r	18·1	16·2	4·4	8
9	·1	16·5	n. r.	9·8	n. a.	2·6	9
10	·6	9·4	3·0	18·9	15·0	7·1	10
11	·8	8·3	0·6	16·8	17·8	7·4	11
12	·7	4·1	0·1	17·4	16·0	6·8	12
13	·2	3·2	0·0	23·0	17·0	8·2	13
14	·8	2·3	n. r.	23·2	13·3	6·0	14
15	·5	2·2	n. r.	7·7	3·0	2·6	15
16	·2	n. r	n. r.	4·6	n. a.	1·8	16
17. 18. 19		..	..	..	..	..	17. 18. 1…
2	…9 Jan. 8)	n. r	n. r.	28·0	7·0	6·5	2
3 & 4	…0	10·5	12·0	9·5	8·0	9·5	3 & 4
5	…5	7·5	9·0	21·0	6·5	10·0	5
6	…0	11·0	12·5	48·0	19·5	10·0	6
7	…5	10·5	8·0	62·0	25·0	13·5	7
8	…5	16·0	n. r.	76·0	33·0	13·5	8
9	…0	12·5	n. r.	14·5	n. a.	7·0	9
10	…5	20·0	12·0	79·0	24·0	14·5	10
11	…5	23·0	12·0	70·0	27·5	10·0	11
12	…5	21·0	13·0	66·0	27·5	13·0	12
13	…0	21·0	14·0	74·0	31·0	14·0	13
14	…0	2[illegible]·5	n. r.	78·0	25·0	12·5	14
15	…5	9·5	n. r.	19·0	9·5	10·0	15
16	…5	n. r.	n. r.	12·0	n. a.	8·0	16
17. 18. 19		..	..	..	..	..	17. 18. 1…
2	…an. 6)	n. r.	n. r.	33	11	12	2
3 & 4		3	0	39	8	15	3 & 4
5		9	0	33	19	9	5
6		5	0	29	23	12	6
7		3	0	28	62	34	7
8		6	n. r.	24	46	33	8
9		132	n. r.	68	n. a.	37	9
10		47	26	24	63	49	10
11		36	5	24	66	49	11
12		20	1	26	55	59	12
13		16	0	30	56	44	1…
14		11	n. r.	29	53	48	1…
15		23	n. r.	41	32	25	1…
16		n. r.	n. r.	38	n. a.	23	1…
17. 18. 19		..	..	..	..	..	17. 1…

…Jan. 10, 1873, 0·9.
„ 10·0.
…nd Oct. 31, 1868 (except Plot 9, Mar. 26, 1867, and Mar. 18, 1868).
…ot 9, Mar. 29, 1871, and Mar. 7, 1872; also Plot 15, Mar. 28, 1872).

Occasional collections from Plot 2 only are, to
entered in the foot-notes.

If the quantity of Nitrogen or Chlorine per millio
water be multiplied by ·226 (more exactly ·226263) th
represent the amount of loss per acre, in lbs., per inch
that strength. Thus, the first entry in the tables, show
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…Jan. 6)	n. r.	n. r.	9·3	0·8	0·8	2
…1	0·3	0·0	3 7	0·6	1·3	3 & 4
…2	0·7	0·0	3·6	1·6	0·9	5
…8	0 5	0 0	13·5	4·5	1·2	6
…4	0·8	0·0	23·0	12·9	4·6	7
…4	0 9	n. r	18·1	15·2	4·4	8
…1	16·5	n. r	9·8	n. a.	2·8	9
…6	9 4	3·0	18·9	15·0	7·1	10
…8	8·3	0 6	16 8	17·8	7·4	11
…7	4·1	0·1	17·4	16·0	6·9	12
…2	3·2	0·0	22 0	17·0	6·2	13
…8	2·3	n. r.	22·2	13·3	6·0	14
…5	2·2	n. r.	7·7	3·0	2·6	15
…2	n. r.	n. r.	4·6	n. a.	1·8	16
	..	.	..	..	..	17. 18. 1…
…0.Jan.6)	n. r	n. r	28·0	7·0	6·6	2
…0	10·5	12·0	9·6	8·0	8·5	3 & 4
…5	7·5	9·0	11·0	8·5	10·0	5
…0	11·0	12·6	48·0	19·5	10·0	6
…5	19·5	8·0	82·0	25·0	13·5	7
…5	16·0	n. r	78·0	33·0	13·5	8
…0	12·5	n. r.	14·5	n. a.	7·0	9
…5	20 0	12·0	79 0	24·0	14·5	10
…5	23 0	12·0	70·0	27 5	16·0	11
…5	21·0	13·0	66·0	27·5	13·0	12
…0	21·0	14·0	74·0	31·0	14·0	13
…0	21 6	n. r.	76·0	25·0	12·5	14
…5	9·5	n. r	19·0	9·5	10·0	15
…5	n. r.	n. r.	12·0	n. a.	8·0	16
	.	.	..	..	..	17. 18. 1…
…an. 6)	n. r.	n. r	33	11	12	2
	3	0	30	8	15	3 & 4
	9	0	33	19	9	5
	6	0	38	23	12	6
	3	0	28	52	34	7
	6	n. r.	24	46	33	8
	132	n. r	68	n. a.	37	9
	47	26	24	63	49	10
	38	6	24	65	49	11
	20	1	26	56	62	12
	15	0	30	66	44	13
	11	n. r.	29	63	48	14
	23	n. r	41	32	25	15
	n. r	n. r	38	n. a.	23	16
	.	..	..	..	..	17. 18. 1…

…Jan. 10, 1872, 0·8.
„ 10·0.
…nd Oct. 31, 1868 (except Plot 9, Mar. 26, 1867, and Mar. 18, 1868).
…lot 9, Mar 23, 1871, and Mar. 7, 1872; also Plot 15, Mar. 26, 1873).

Where more than one date or hour of collection is given at the head of a column, the results relate to mixtures of such separate collections.

Where figures are entered in square brackets, thus [ ], they represent the mean result of two or more analyses of successive collections from the same or closely consecutive runnings; and in such case the details will be found in the proper place in Table III.

When results are entered in a bracket thus ( ), they refer to samples collected at some other hour or date than that given at the head of the column; and the hour or date is given.

Occasional collections from Plot 2 only are, to save a column, entered in the foot-notes.

If the quantity of Nitrogen or Chlorine per million of drainage-water be multiplied by ·226 (more exactly ·226263) the product will represent the amount of loss per acre, in lbs., per inch of drainage of that strength. Thus, the first entry in the tables, shows 19·6 Nitrogen as Nitric Acid, per million drainage-water, and we have 19·6 × ·226 = 4·43 lbs. Nitrogen lost per acre, per inch of drainage of that strength.

N…LK EXPERIMENTAL WHEAT-FIELD, ROTHAMSTED.

Plots.	… P.M.	June 2, 9 P.M. — Rain: 9 A.M. 0·06 June 1. 0·56 „ 2. — Moderate.	June 3, 7 A.M. — Rain: 9 A.M. 0·70 June 3. — Continued Small.	June 11, 7–8 P.M. — Rain: 9 A.M. 0·03 June 11. 0·92 „ 12. — Almost full.	June 13, 6 A.M. — Rain 9 A.M. 0·29 June 13. — Small, variable.	Plots.
2	. r.	2·0	2·3	1·4	n. r.	2
3 & 4	1·6	0·0	0 9	0·0	n. a.	3 & 4
5	2·0	0·0	1 5	0·0	1·2	5
6	5·4	0·9	4·0	0·4	2·9	6
7	9·7	3·0	6·5	2·1	4·3	7
8	0·9	9·3	13 6	6·0	n. r.	8
9	3·3	12·0	31·7	16·6	21·4	9
10	3·5	16·2	25·7	17·7	20·8	10
11	0·9	10·7	18·6	9·9	14 2	11
12	5·2	7·8	13·3	6·7	8·9	12
13	2·5	4·3	7·9	2·2	5·1	13
14	5·2	7·3	10·5	5 2	n. r.	14
15	·6	3 2	7·9	3·9	n. r.	15
16	·9	0 0	n. r.	0·0	n. r.	16
17	·9	0·0	1·5	0·2	1·9	17
18	·0	3·9	7·7	2·0	n r.	18
19	·3	1·2	n. r.	0·9	n. r.	19
2	r	0·4	0·4	0·3	n. r.	2
3 & 4	2·9	0·8	2 3	1·3	n. a.	3 & 4
5	·6	0·6	3·1	1·1	3·2	5
6	·7	12·6	23·6	7·1	18·7	6
7	·6	22 3	43·0	22·8	26·7	7
8	·3	38·9	58·4	32·3	n. r.	8
9	·0	2 2	7·6	3·8	6·0	9
10	·1	34·8	61·4	39 5	49·0	10
11	·1	37·1	66·9	38·3	52·6	11
12	·3	25·8	69·8	37 3	43·4	12
13	1	33·9	63 1	31·7	46·2	13
14	0	34·8	43·3	37·4	n. r.	14
15	3	4·5	12·1	6·0	n. r.	15
16	1	1·5	n. r.	1·8	n. r.	16
17	·1	2 5	7·3	3·7	7·2	17
18	·4	28·7	68·7	24·7	n. r.	18
19	7	1·7	n. r.	1·6	n. r.	19
2	r.	[illegible]	575	467	n. r.	2
3 & 4	5	0	39	0	n. a.	3 & 4
5	7	0	48	0	38	5
6	3	7	17	6	16	6
7	3	14	15	9	16	7
8	9	24	24	19	n. r.	8
9	6	546	417	437	357	9
10	3	47	42	45	42	10
11	1	29	28	26	27	11
12	6	22	22	18	21	12
13	9	13	13	69	11	13
14	5	21	24	14	n. r.	14
15	2	71	66	65	n. r.	15
16	1	0	n r.	0	n. r.	16
17	7	0	21	5	26	17
18	8	13	14	8	n. r.	18
19	6	71	n. r.	66	n. r.	19

…cake) October 15, 1878.

)ADBALK EXPERIMENTAL WHEAT-FIELD, ROTHAMSTED.

(STED.

PLOTS.	Nov 28, 3.10 P.M. — Rain 9 A.M. 0·84 Nov. 28. 0·09 „ 29. Long continued, Moderate.	Dec. 27, 11–12 A.M. — Rain 9 A.M. 0·47 Dec. 25–27 0·21 „ 28. Small.	Dec. 30, 10 A.M. — Rain 9 A.M. 0·10 Dec. 29. 0·20 „ 30 Dribbling.	1879 (4). Jan. 3, 1–3 P.M. — Rain: 9 A.M. 0·51 Jan. 2. 0·53 „ 3. Full.	1879 (4). Jan. 14, 10–11 A.M. — Rain: 9 A.M. 0·16 Jan. 13. 0·95 „ 14. 0·64 „ 15. Full.	PLOTS.
2	n. r.	n. r	n. r	7·7	8·5 (8·4, 3.30 P.M.)	2
3 & 4	5·5	4·6	7·5	6·6	4·2	3 & 4
5	4·9	4 2	7·8	6·0	3·4	5
6	4·9	3·8	8·6	5·8	3·1	6
7	3·9	(0·6 Dec. 26) 3·6	7·9	5·3	2·7	7
8	6·7	3·6	11·0	7·7	4·4	8
9	9·9	n. r.	14·4	9·4	4·1	9
10	7·6	4·4	9·0	7·7	4·3	10
11	6·7	4·4	8·8	8·3	4·4	11
12	5·9	3·9	7·1	6·6	3·7	12
13	6·5	3·8	8·4	6·9	3·6	13
14	6·6	n. r.	n. r.	8·4	4·7	14
15	32·9	n. r.	n. r.	34·7	16·1	15
16	5·4	n. r.	n r.	8·2	4·5	16
17	4·0	3·2	8·5	5·4	2·5	17
18	4·9	n. r.	n. r.	7·4	4·2	18
19	(11·6, 11 A.M.) 13·3	n. r.	n. r.	14·2	8·5	19
2	n. r.	n. r.	n. r.	6·2	6·3 (6·6, 3.30 P.M.)	2
3 & 4	8 0	5·1	6·0	6·0	4·2	3 & 4
5	8·5	5·7	9·2	7·4	3·6	5
6	12 8	5·8	17·2	8·3	4·6	6
7	17·6	(2·6 Dec. 26) 5·2	23·4	9·4	5·1	7
8	36·7	6·0	41·7	18·9	11·4	8
9	8 6	n. r.	10·6	6·5	3·7	9
10	23·6	6·1	19·6	12·6	8·2	10
11	25 4	7·0	27·3	16·6	9·7	11
12	25·6	6·6	22·1	15·1	8·2	12
13	25 9	6·2	21·9	17·4	8·9	13
14	22·1	n. r	n. r.	16·6	9·9	14
15	51·5	n. r.	n. r.	42·9	19·8	15
16	6 8	n. r.	n. r.	6·1	3·7	16
17	19·2	5·3	19·8	13·1	7·6	17
18	8·7	n. r	n. r.	6·1	4·8	18
19	(8·3, 11 A.M.) 8·3	n. r.	n. r.	7·3	5·6	19
2	n. r.	n. r.	n. r.	124	135 (129, 3.30 P.M.)	2
3 & 4	60	90	94	110	100	3 & 4
5	68	74	65	81	94	5
6	38	66	50	70	67	6
7	22	(24·0 Dec. 26) 68	34	66	63	7
8	16	58	26	41	39	8
9	115	n r	136	145	111	9
10	32	72	46	61	48	10
11	26	63	32	60	48	11
12	23	60	32	44	46	12
13	21	61	29	40	40	13
14	30	n. r.	n. r.	61	48	14
15	64	n. r.	n. r.	81	76	15
16	79	n. r.	n r.	134	132	16
17	21	60	33	41	38	17
18	73	n. r	n. r.	121	108	18
19	(140, 11 A.M.) 160	n. r.	n. r.	196	170	19

…s 9 and 16, April 11, 1877 (Plot 2 dung, Nov. 1, 1877), and Plot 16 again Nov. 3, 1877.
…ar. 14, 1878; and Plot 15, Nov. 3, 1877, and Plots 16 and 19, Oct. 18, 1878.
…Rapecake) Oct. 15, 1878.

[redacted]

N... LK EXPERIMENTAL WHEAT-FIELD, ROTHAMSTED.

...D.

PLOTS.	... P.M.	June 2, 9 P.M. — Rain: 9 A.M. 0·06 June 1. 0·56 „ 2. — Moderate.	June 3, 7 A.M. — Rain: 9 A.M. 0·70 June 3. — Continued Small.	June 11, 7–8 P.M. — Rain: 9 A.M. 0·03 June 11. 0 92 „ 12. — Almost full.	June 12, 6 A.M. — Rain 9 A.M. 0·29 June 13. — Small, variable.	PLOTS.
2	. r	2·0	2·3	1·4	n. r.	2
3 & 4	·6	0·0	0 9	0·0	n a.	3 & 4
5	2·0	0·0	1·6	0·0	1·2	5
6	5·4	0·9	4·0	0·4	2·9	6
7	9 7	3·0	6·6	2·1	4·3	7
8	0·9	9·3	13 8	6 0	n. r.	8
9	3·3	12·0	31·7	16·6	21 4	9
10	3·5	16·2	25·7	17 7	20·8	10
11	0·9	10·7	18·6	9·9	14 3	11
12	6·2	7·8	13·3	6·7	8·9	12
13	2·5	4·3	7·9	2 2	6 1	13
14	6 2	7·3	10 5	5 2	n. r.	14
15	7·6	3·2	7·9	3 9	n. r.	15
16	·9	0·0	n. r.	0·0	n. r.	16
17	·9	0·0	1·6	0·2	1·9	17
18	·9	3 9	7·7	2·0	n. r.	18
19	·3	1·2	n. r.	0·9	n. r	19
2	r.	0·4	0·4	0·3	n. r.	2
3 & 4	·9	0·8	2 3	1·3	n. a.	3 & 4
5	·5	0·6	3·1	1·1	3·2	5
6	·7	12·6	23·6	7·1	18·7	6
7	·6	22·3	43·0	22 8	26·7	7
8	·3	38·9	58·4	32·3	n. r	8
9	·0	2 2	7·6	3·8	6·0	9
10	·1	34·8	61·4	30 6	49·0	10
11	·1	37·1	66·9	38·3	52·6	11
12	·3	36·8	59·8	37·3	43·4	12
13	·1	33·9	63·1	31·7	45·2	13
14	·0	34·6	43·3	37·4	n. r.	14
15	·3	4·5	12·1	6·0	n r.	15
16	1	1·5	n. r.	1·8	n. r.	16
17	·1	2 5	7·3	3·7	7·2	17
18	4	29·7	56·7	24·7	n. r.	18
19	·7	1·7	n. r.	1·6	n. r.	19
2	r.	800	675	467	n. r.	2
3 & 4	5	0	39	0	n. a.	3 & 4
5	7	0	48	0	38	5
6	3	7	17	6	16	6
7	3	14	15	9	16	7
8	9	24	24	19	n. r.	8
9	6	546	417	437	357	9
10	3	47	42	48	42	10
11	1	29	28	26	27	11
12	6	22	22	18	21	12
13	9	13	13	69	11	13
14	5	21	24	14	n. r.	14
15	2	71	65	65	n. r.	15
16	1	0	n. r.	0	n. r.	16
17	7	0	21	5	26	17
18	8	13	14	8	n. r.	18
19	6	71	n. r.	56	n. r.	19

... cake) October 16, 1878.

m Broadbalk Experimental Wheat-Field, Rothamsted.

)THAMSTED.

	Oct. 1, 9–10 A.M. — Rain: 9 A.M. 0·54 Sept. 29. 0·42 Oct. 1. — Slow dribble.	1880 ([2]). Feb. 8, 8 A.M. — Rain: 9 A.M. 0·03 Feb. 6. 0·09 „ 7. 0·30 „ 8. — Very small.	Mix. Feb. 16,17, 19. — Rain: 9 A.M. 1.56 Feb. 15–19. — Flow, Feb. 16 & 17. Moderate; Feb. 19, Small.	April 15. 3.30 to 4 P.M. — Rain: 9 A.M. 0·16 Apr. 14. 0·45 „ 15. 0·18 „ 16. — Small.	April 15. 6 to 6.30 P.M.	Plots.
TER.						
r.	n. r.	n. r.	[27·3]	n. r.	n. r.	2
0	1·6	12·8	13·5	(5·2 Ap. 14) 4·6	5·1	3 & 4
0	1·5	16·8	16·8	5·6	6·6	5
0	0·5	n. r.	16·2	16·0	14·4	6
0	1·5	19·7	15·9	(23·2 Ap. 14) 32·2	31·9	7
6	n. a.	n. r.	22·1	27·6	27·6	8
6	3·3	n. r.	[17·8]	66·7	n. r.	9
4	4·2	n. r.	17·1	22·9	24·8	10
9	1·2	18·9	22·7	19·1	19·7	11
6	2·3	18·9	[22·8]	21·3	20·3	12
4	1·4	17·6	[20·6]	30·7	21·0	13
8	n. r.	n. r.	21·1	n. r.	n. r.	14
7	n. r.	n. r.	[78·9]	n. r.	n. r.	15
0	n. r.	n. r.	15·9	6·5	6·6	16
0	0·8	16·5	16·0	27·0	21·3	17
2	1·1	n. r.	16·5	n. r.	n. r.	18
r.	n. r.	n. r.	33·0	n. r.	n. r.	19
:.	n. r.	n. r.	[15·7]	n. r.	n. r.	2
7	5·8	12·4	9·9	(6·9 Ap. 14) 6·9	7·1	3 & 4
8	5·1	14·0	11·7	7·0	7·2	5
2	13·3	n. r.	15·0	51·2	48·4	6
4	17·6	22·7	17·6	(82·0 Ap.14) 138·8	137·4	7
2	n. a.	n. r.	22·5	98·0	97·4	8
1	5·4	n. r.	[10·5]	10·0	n. r.	9
6	16·7	n. r.	15·7	90·0	87·2	10
8	17·6	22·8	20·5	55·2	52·5	11
2	18·3	23·5	[21·1]	57·5	53·7	12
7	18·1	25·0	[22·1]	92·7	69·1	13
5	n. r.	n. r.	21·0	n. r.	n. r.	14
3	n. r.	n. r.	[128·7]	n. r.	n. r.	15
5	n. r.	n. r.	10·0	6·8	6·5	16
4	3·3	12·3	9·9	96·0	85·2	17
7	16·2	n. r.	21·7	n. r.	n. r.	18
:.	n. r.	n. r.	15·1	n. r.	n. r.	19
r.	n. r.	n. r.	[174]	n. r.	n. r.	2
	28	103	136	(75 Apr. 14) 67	72	3 & 4
	29	120	144	80	92	5
	4	n. r.	108	31	30	6
	9	87	90	(28 Apr. 14) 23	23	7
	n. a.	n. r.	98	28	28	8
	61	n. r.	[170]	667	n. r.	9
	25	n. r.	109	25	28	10
	7	83	111	35	38	11
	13	80	[108]	37	38	12
	8	70	[93]	33	30	13
	n. r.	n. r.	101	n. r.	n. r.	14
	n. r.	n. r.	[61]	n. r.	n. r.	15
	n. r.	n. r.	159	96	162	16
	24	134	162	28	25	17
	7	n. r.	76	n. r.	n. r.	18
r.	n. r.	n. r.	219	n. r.	n. r.	19

. Manures sown March 13, 1879, and March 9, 1880; except (Plot 2 dung), Plot 15, and

…en as Nitrates, and Chlorine (also Nitrogen to 100 Chlorine) in …age-Waters from Broadbalk Experimental Wheat-Field, Rothamsted.

…ppendix Table II.—*continued.* Determinations made at Rothamsted.

1882—*continued* ([1]).							
March 1,		March 2.	April 26.		April 28. 8–8·30, and 12 noon, mixed.	April 29. 2, 4 & 6 P.M. mixed.	May 6. 6 & 9 A.M. mixed.
6–7 A.M.	10-11 A.M.	6–7 A.M.	6–7 A.M.	9 A.M.			
Rain: 9 A.M. 0·61 Feb. 28. 0·22 Mar. 1. Small.		Rain: 9 A.M. 0·22 Mar. 1. 0·03 „ 2. Dribbling.	Rain: 9 A.M. 1·05 April 25. 0·01 „ 26. Small.		Rain: 9 A.M. 0·45 Ap. 27. 0·13 „ 28. Small.	Rain: 9 A.M. 0·52 Ap. 29. Small.	Rain: 9 A.M. 0·84 May 5. Moderate, had been freer.
Nitrogen as Nitric Acid, per Million Drainage Water.							
4·5	n. r.	n. r.	n. r.	n. r.	n. r.	n. r.	trace
2·6	1·9	n. r.	0·2	0·0	0.0	0·0	0·0
2·4	2·9	n. r.	0·1	0·2	0·0	0·0	0·0
7·7	5·0	5·7	0·6	0·6	0·4	0·2	trace
14·4	12·0	n. r.	2·2	n. r.	2·5	1·7	0·6
14·1	12·0	n. r.	n. r.	n. r.	n. r.	9·3	6·2
119·2	96·6	n. r.	n. r.	n. r.	n r.	6·6	6·0
15·2	14·1	11·8	35·2	33·3	26·6	23·4	20·0
15·6	12·5	11·1	20·2	17·3	14·7	10·5	5·2
13·1	10·2	8·4	5·8	4·1	3·9	2·9	1·3
13·9	10·0	9·1	6·3	5·1	4·9	3·1	1·5
13·2	n. r.	n. r.	n. r.	n. r.	n. r.	3·2	1·9
11·8	17·3	n. r.	2·0	n. r.	n. r.	1·4	1·6
1·4	1·5	n. r.	trace	trace	trace	trace	trace
10·3	8·5	7·1	4·5	3·0	1·9	1·3	0·2
3·4	3·9	n. r.	trace	trace	trace	0·0	0·1
9·9	10·5	n. r.	n. r.	n. r.	n. r.	0·2	0·1
Chlorine per Million Drainage Water.							
4·1	n. r.	n. r.	n. r.	n. r.	n. r.	n. r.	3·0
3·5	3·4	n. r.	2·0	2·6	2·0	2·3	2·6
3·3	3·0	n. r.	2·9	3·9	2·2	1·9	3·2
62·4	54·6	33·2	20·9	21·0	17·4	16·1	8·7
149·6	105·2	n. r.	31·8	n. r.	27·7	28·6	30·1
146·4	101·0	n. r.	n. r.	n. r.	n. r.	40·3	47·8
9·0	9·9	n. r.	n. r.	n. r.	n. r.	1·4	2·0
121·5	89·0	54·0	70·5	72·6	57·1	51·6	54·0
134·9	104·9	72·4	75·7	76·0	64·0	57·5	55·1
120·7	98·0	58·0	52·8	54·0	45·2	45·4	43·2
136·0	96·0	65·6	53·8	55·3	50·8	47·6	44·2
168·0	n. r.	n. r.	n. r.	n. r.	n. r.	42·6	45·0
15·2	26·0	n. r.	13·0	n. r.	n. r.	10·9	11·3
3·1	2·5	n. r.	2·6	2·8	2·7	2·5	3·6
164·0	119·4	84·0	48·0	51·0	40·0	37·7	35·5
12·1	14·2	n. r.	6·6	6·3	5·2	5·3	7·5
4·8	5·0	n. r.	n. r.	n. r.	n. r.	1·3	1·8
Nitrogen as Nitric Acid to 100 Chlorine.							
110	n. r.	n. r.	n. r.	n. r.	n. r.	n. r.	trace
74	56	n. r.	10	0	0	0	0
73	97	n. r.	3	5	0	0	0
12	9	17	3	3	2	1	trace
10	11	n. r.	7	n. r.	9	6	2
10	12	n. r.	n. r.	n. r.	n. r.	23	13
1324	976	n. r.	n. r.	n. r.	n. r.	614	300
13	16	22	50	5	47	46	37
12	12	15	27	23	23	18	9
11	10	15	11	8	9	6	3
10	10	14	12	9	10	7	2
8	n. r.	n. r.	n. r.	n. r.	n. r.	8	4
8	67	n. r.	15	n. r.	n. r.	13	14
4	60	n. r.	trace	trace	trace	trace	trace
6	7	9	9	6	5	3	1
28	28	n. r.	trace	trace	trace	0	1
206	210	n. r.	n. r.	n. r.	n. r.	15	6

…2 *continued.* Nit. manures sown Feb. 23, 1882; except (Plot 2 dung, Oct. 30) Plot 15, and Plot 19 (Rape-…t 15, Oct. 25, 1881.

…en that some of the samples of the first collection on March 1, after the Nitrogenous manures had only been …e days, show higher Chlorine than any previous samples during the whole series of years. The Nitrogen … …d from the *Nitrate Plot 9, is also* higher than on any previous collection. The Chlorine is, however, … …d *Nitrogen as Nitric acid also* lower, in the samples of the second collection of the same date. They …r *on the next day, March 2,* when only a few of the drains ran.

…s, and CHLORINE (also NITROGEN to 100 CHLORINE) in DRAINAGE-W…
EXPERIMENTAL WHEAT-FIELD, ROTHAMSTED.

…NDIX TABLE III.—Frequent Collections during the same Runnings from selec…

DETERMINATIONS made at ROTHAMSTED.

…n Nitric Acid, per Million.		Chlorine per Million.			…
Plot 12.	Plot 13.	Plot 9.	Plot 12.	Plot 13.	Plot 9
…il 7. Rain, 9 A.M., 0·06 April 6, 0·53 April 7. Small. Nit. Manures sown Mar…					
25·4	29·4	13·4	83·4	161·4	356
n. a.	n. a.	n. a.	69·6	63·6	n. a.
18·2	20·1	n. a.	56·8	70·0	[illegible]
n. a.	n. a.	n. a.	[illegible]		

12 Noon.	n. r.	12·9	8·0	n. r.	56·9	57·3	n. r.	23	14
3 P.M.	n. r.	n. r.	8·0	n. r.	n. r.	54·8	n. r.	n. r.	15
1879. June 12. Rain, 9 A.M., 0·03 June 11, 0·92 June 12, 0·29 June 13. Small.									
6–7 A.M.	21·4	8·9	5·1	6·0	43·4	45·2	357	21	11
8 A.M.	n. a.	8·2	5·3	n. a.	41·2	42·6	n. a.	20	12
9 A.M.	n. a.	8·1	5·3	n. a.	41·7	lost	n. a.	19	n. a.
11 A.M.	n. a.	n. a.	4·9	n. a.	n. a.	38·7	n. a.	n. a.	13
1 P.M.	n. a.	n. a.	4·4	n. a.	n. a.	42·7	n. a.	n. a.	10
3 P.M.	20·8	n. a.	4·0	6·4	n. a.	40·2	325	n. a.	10
5 P.M.	20·5	n. a.	4·4	6·4	n. a.	40·5	320	n. a.	11
7 P.M.	n. a.	n. a.	4·0	n. a.	n. a.	42·6	n. a.	n. a.	9
7.30 P.M.	18·0	7·1	n. r.	5·8	38·6	n. r.	310	18	n. r.
1879. July 1. Rain, 9 A.M., 0·70 July 1, 0·38 July 2. Moderate.									
10 A.M.	3·0	1·7	0·5	1·7	21·7	22·9	177	8	2
12 Noon.	6·1	2·1	0·5	2·2	30·1	23·6	277	7	2
2 P.M.	12·1	2·9	0·9	3·3	33·1	34·7	367	9	3
4 P.M.	13·8	2·9	0·7	3·3	35·7	32·6	418	8	2
6 P.M.	15·7	3·4	0·4	4·2	36·2	30·6	374	9	1
7 P.M.	15·3	n. a.	n. a.	4·2	n. a.	n. a.	364	n. a.	n. a.
8 P.M.	n. r.	3·5	0·9	n. r.	36·8	36·7	n. r.	10	3
1879. July 22. Rain, 9 A.M., 0·38 July 20, 0·46 July 21, 0·36 July 22. Small.									
4–5 P.M.	6·0	0·8	0·0	3·1	32·2	31·6	194	3	0
6 P.M.	5·8	0·8	0·2	2·4	31·9	31·7	242	3	1
8 P.M.	5·8	0·7	0·0	3·1	29·5	31·4	187	2	0
9 P.M.	n. r.	0·8	0·0	n. r.	31·2	31·7	n. r.	3	0
11 P.M.	n. r.	n. r.	0·0	n. r.	n. r.	31·6	n. r.	n. r.	0
1879. August 3. Rain, 9 A.M., 0·69 August 1, 0·02 August 2, 3·00 August 3. Very full.									
7–8 A.M.	1·6	0·6	0·0	0·9	16·2	18·4	178	4	0
10 A.M.	1·2	0·2	0·2	0·9	20·2	20·8	133	1	1

ES, and CHLORINE (also NITROGEN to 100 CHLORINE) in DRAINAGE-W EXPERIMENTAL WHEAT-FIELD, ROTHAMSTED.

: TABLE III —*continued*.—Frequent Collections during the same Runnings fro

DETERMINATIONS MADE AT ROTHAMSTED.

as Nitric Acid per Million.		Ch[illegible] per Million.			
Plot 12.	Plot 13.	Plot 9.	Plot 12.	Plot 13.	Plot
9. August 20. Rain, 9 A.M., 0·57 Aug. 18; 0·01 Aug. 19; 1·02 Aug. 20. Mo					
0·4	0·3	1·6	18·5	20·6	0
0·6	0·4	1·9	19·8	22·4	111
1·0	0·4	2·0	23·6	24·7	160
1·0	0·4	2·4	24·7	26·5	175
0·8	0·4	n. r.	25·4	27·3	n. r.
9. August 23. Rain, 9 A.M., 0·07 Aug. 22; 0·13, Aug. 23; 0·30 Aug. 24					

	Plot 9.	Plot 12.	Plot 13.	Plot 15.	Plot 9.	Plot 12.	Plot 13.	Plot 15.
1880. February 16. Rain, 9 A.M., 0·18, Feb. 15; 0·26 Feb. 16. Moderate. Nit. manures sown Mar. 13, 1879 (except Plot 15, Oct, 26, 1879).								
11–11.30 A.M.	20·5	n. a.	n. a.	83·2	12·7	22·9	23·0	152·0
12–1 P.M.	21·1	24·9	21·5	85·2	11·7	21·7	22·7	146·0
3 P.M.	n. a.	n. a.	n. a.	82·7	n. a.	n. a.	n. a.	138·8
4–5 P.M.	n. a.	n. a.	21·1	79·2	n. a.	23·4	25·0	128·8
1880. February 17. Rain, 9 A.M., 0·63 Feb. 17; 0·02 Feb. 18. Moderate.								
7–8 A.M.	15·7	23·3	20·2	82·2	9·2	19·9	20·7	129·4
12–12.30 Noon	19·9	23·3	22·1	78·7	10·7	21·2	23·0	117·2
4 P.M.	n. a.	n. a.	n. a.	67·8	10·6	19·5	23·5	103·8
1880. February 19. Rain, 9 A.M., 0·47 Feb. 19; 0·21 Feb. 20. Small.								
7–8 A.M.	17·1	20·2	20·2	71·2	9·7	20·6	22·7	104·8
12 Noon.	n. a.	n. a.	n. a.	69·8	9·4	18·8	20·7	102·0
4 P.M.	16·5	19·6	19·6	70·8	9·8	20·2	21·7	104·8

	Nitrogen as Nitric Acid per Million.			Chlorine per Million.			Nitrogen to 100 Chlorine.		
	Plot 9.	Plot 12.	Plot 13.	Plot 9.	Plot 12.	Plot 13.	Plot 9.	Plot 12.	Plot 13.
1880. April 15. Rain, 9 A.M., 0·16 Apr. 14; 0·45 Apr. 15. Small. Nit. manures sown March 9, 1880.									
4 P.M.	66·7	21·3	30·7	10·0	57·5	92·7	667	37	33
5 P.M.	n. r.	21·3	23·5	n. r.	56·7	76·6	n. r.	38	31
6 P.M.	n. r.	n. a.	n. a.	n. r.	54·6	70·7	n. r.	n. a.	n. a.
6.30 P.M.	n. r.	20·3	21·0	n. r.	53·7	69·1	n. r.	38	30
7 P.M.	n. r.	20·3	20·7	n. r.	54·4	69·0	n. r.	37	30
1880. September 14. Rain, 9 A.M., 1·79 Sept. 12; 0·44 Sept. 13; 0·05 Sept. 14. Full.									
1.45 P.M.	30·8	8·4	7·7	12·0	81·3	102·8	257	10	8
3.15–4.15 P.M.	35·1	7·5	6·5	11·8	81·8	101·4	298	9	6
6.30 P.M.	14·2	7·7	6·9	8·0	41·9	51·2	178	18	14
1880 September 15. Rain 9 A.M., 1·85 Sept. 15. Moderate.									
6.30 A.M.	n. a.	n. a.	n. a.	9·9	54·7	64·8	n. a.	n. a.	n. a.
9.30 A.M.	13·9	6·7	6·2	10·3	59·1	69·8	135	11	9
12 Noon.	14·7	6·7	6·0	9·1	59·7	75·2	162	11	8
1880. September 16. Rain 9 A.M., 0·98 Sept. 16. Full.									
10.30–11 A.M.	10·8	6·0	5·4	8·2	48·6	58·7	132	12	9
12.30 Noon.	n. a.	n. a.	n. a.	9·1	50·1	61·7	n. a.	n. a.	n. a.

Nitrogen as Nitrates, and Chlorine (also Nitrogen to 100 Chlorine) in Drainage-Waters from Broadbalk Experimental Wheat-Field, Rothamsted.

APPENDIX TABLE III.—*continued.* Frequent Collections during the same Runnings from selected Plots.

Determinations made at Rothamsted.

Hours of Collection.	Nitrogen as Nitric Acid per Million.			Chlorine per Million.			Nitrogen to 100 Chlorine.		
	Plot 9.	Plot 12.	Plot 13.	Plot 9.	Plot 12.	Plot 13.	Plot 9.	Plot 12.	Plot 13.
1880. October 7. Rain, 9 A.M., 0·67 Oct. 5; 0·26 Oct. 6; 1·24 Oct. 7. Half full.									
8.30–9 A.M.	10·6	7·6	8·6	4·6	17·9	23·7	230	43	36
12 Noon.	10·7	9·3	7·8	5·4	31·3	40·7	198	30	19
2–3 P.M.	11·8	9·3	8·4	6·4	34·3	39·0	184	27	22
1880. October 10. Rain, 9 A.M., 0·16 Oct. 8; 0·03 Oct. 9; 0·55 Oct. 10. Moderate.									
10 A.M.	13·1	8·6	7·6	5·6	32·8	37·8	234	26	20
2 P.M.	15·3	8·8	n. a.	6·1	37·1	42·2	251	24	n. a.
	Plot 7.	Plot 9.	Plot 15.	Plot 7.	Plot 9.	Plot 15.	Plot 7.	Plot 9.	Plot 15.
1880. October 27. Rain, 9 A.M., 0·74 Oct. 27. Small. Nit. manures sown Mar. 9, 1880 (except Plot 15, Oct. 25, 1880).									
6·30 A.M.	5·9	10·8	13·5	26·1	6·6	146·4	23	164	9
9 and 11 A.M.	n. a.	n. a.	12·4	n. a.	n. a.	118·2	n. a.	n. a.	11
1 P.M.	6·7	11·6	12·9	30·7	6·3	116·6	22	184	11
3 and 5 P.M.	n. a.	n. a.	13·0	n. a.	n. a.	109·4	n. a.	n. a.	12
1880. October 28. Rain, 9 A.M., 0·59 Oct. 28. Moderate.									
6·30 A.M.	7·2	12·6	13·3	27·7	5·7	82·6	26	221	16
10·45 A.M.	n. a.	n. a.	18·2	n. a.	n. a.	97·2	n. a.	n. a.	19
11 A.M. & 3 P.M.	5·0	7·2	18·0	15·7	5·3	101·4	32	136	18
5 P.M.	n. a.	n. a.	16·0	n. a.	n. a.	94·0	n. a.	n. a.	17
1880. October 29. Rain, 9 A.M., 0·78 Oct. 29. Slackening, after full.									
10·30 A.M.	5·9	9·3	16·9	20·7	5·6	80·8	29	166	21
4 P.M.	n. a.	n. a.	14·0	n. a.	n. a.	66·6	n. a.	n. a.	21
1880. November 15. Rain, 9 A.M., 0·19 Nov. 14; 0·27 Nov. 15. Moderate.									

1880. November 19. Rain, 9 A.M., 0·01 Nov. 18; 0·54 Nov. 19. Moderate.

7.30 A.M.	3·9	6·6	33·4	13·6	3·9	37·5	29	169	89
Noon.			37·1			52·1			71
4 P.M.	n. a.	n. a.	32·1	n. a.	n. a.	58·3	n. a.	n. a.	55
1880. November 26. Rain, 9 A.M., 0·33 Nov. 25; 0·23 Nov. 26; 0·13 Nov. 27. Moderate.									
11 A.M.	5·1	8·5	31·0	21·5	5·2	42·0	24	164	74
2 P.M.	5·6	9·3	37·8	22·5	4·1	46·4	25	227	82
4 P.M.	n. a.	n. a.	36·0	n. a.	n. a.	48·5	n. a.	n. a.	74
1880. December 22. Rain, 9 A.M., 0·44 Dec. 20; 0·06 Dec. 21; 0·20 Dec. 22. Small.									
11 A.M.	1·2	2·2	n. a.	5·7	1·7	10·3	21	129	n. a.
2 P.M.	2·9	4·5	22·6	6·2	2·5	21·6	47	180	105
4.30 P.M.	2·5	n. a.	23·2	5·8	2·4	22·4	43	n. a.	104
1880. December 29. Rain, 9 A.M., 0·19 Dec. 27; 0·39 Dec. 28; 0·05 Dec. 29. Moderate.									
3.30–4 P.M.	2·7	3·4	15·2	8·6	3·3	17·9	31	103	85
5 P.M.	3·4	4·8	17·9	8·7	2·7	18·7	39	178	96
1880. December 30. Rain, 9 A.M., 0·58 Dec. 30; 0·08 Dec. 31. Slow.									
1–2 P.M.	4·1	5·9	23·2	12·7	2·7	27·0	32	219	86
3–4 P.M.	4·6	6·9	28·1	14·7	3·9	31·5	31	177	89
1881. January 29. Rain, 9 A.M., 0·10 Jan. 27; 0·10 Jan. 28; 0·07 Jan. 29. Moderate.									
11 A.M.	3·1	n. r.	2·7	8·7	n. r.	9·7	36	n. r.	28
2–3 P.M.	3·6	n. r.	3·2	6·9	n. r.	7·7	52	n. r.	42
4–5 P.M.	4·3	n. r.	4·3	7·6	n. r.	7·3	57	n. r.	59
1881. January 30. Rain, 9 A.M., 0·28 Jan. 30; 0·08 Jan. 31. Small.									
8 A.M.	n. a.	5·5	n. a.	n. a.	7·5	n. a.	n. a.	73	n. a.
4–5 P.M.	n. a.	4·5	n. a.	n. a.	7·3	n. a.	n. a.	62	n. a.
1881. February 2. Rain, 9 A.M., 0·01 Feb. 1; 0·22 Feb. 2; 0·33 Feb. 3. Small.									
11 A.M.	6·3	8·0	n. r.	7·8	5·7	n. r.	81	140	n. r.
3 P.M.	6·1	7·2	28·7	8·0	5·1	22·6	76	141	127
4–5 P.M.	6·7	7·7	27·8	8·6	5·0	20·6	78	154	135

, and Chlorine (also Nitrogen to 100 Chlorine) in Drainage-W

Experimental Wheat-Field, Rothamsted.

TABLE III.—*continued.* Frequent Collections during the same Runnings from

Determinations made at Rothamsted.

Nitric Acid, per Million.		Chlorine per Million.			
Plot 9	Plot 15.	Plot 7.	Plot 9.	Plot 15.	Plot 7.
1881. February 8 Rain, 9 A.M., 0·93 Feb. 8; 0·06 Feb 9. Moderate.					
4·3	14·9	6·7	4·7	13·7	45
6·7	20·8	8·1	4·6	18·6	62
7·7	25·7	10·4	4·7	22·7	61
1881 February 10. Rain, 9 A.M., 0·65 Feb. 10; 0·11 Feb. 11. Moderate.					
5·1	16·4	7·1	4·2	15·6	61
6·6	20·2	9·0	4·5	18·6	59
7·2	23·6	9·8	4·7	20·9	60

1881. March 5. Rain 9 A.M. ...

12 Noon.	12·1	n. r.	39·5	[illegible]	n. r.	[illegible]	[illegible]		
2 P.M.	12·4	n. r.	37·0	28·8	n. r.	55·4	43	n. r.	67
1881. December 7. Rain, 9 A.M., 0·19 Dec. 6; 0·54 Dec. 7. Moderate.									
8 A.M.	10·2	13·8	33·2	27·6	7·1	51·6	37	194	64
10 A.M.	11·4	n. r.	36·3	34·9	n. r.	57·4	33	n. r.	63
12 Noon.	11·2	n. r.	n. a.	35·2	n. r.	n. a.	32	n. r.	n. a.
1881. December 17. Rain, 9 A.M., 0·26 Dec. 15; 0·21 Dec. 16; 0·34 Dec. 17. Full.									
8 A.M.	6·0	6·2	16·8	14·7	3·9	26·9	41	159	63
12 Noon.	9·7	13·7	34·2	28·7	16·5	52·1	34	83	66
4 P.M.	3·0	3·7	11·8	5·9	2·9	18·8	51	128	63
1881. December 18. Rain, 9 A.M., 1·25 Dec. 18. Moderate.									
	4·3	6·3	22·7	9·5	9·4	33·6	45	67	68
	8·0	8·6	31·2	21·1	5·2	46·0	38	165	68
	9·0	9·8	33·6	24·9	6.0	51·1	36	163	66
1881. December 20. Rain, 9 A.M., 0·37 Dec. 20. Moderate.									
	6·2	7·4	16·5	17·3	3·8	26·8	36	195	62
	7·5	10·7	27·0	22·0	5·6	41·9	34	191	64
	9·2	11·4	29·1	24·9	6·2	47·0	33	184	62
1881. December 21. Rain, 9 A.M., 0·42 Dec. 21. Extensive.									
	8·1	11·0	30·9	23·7	6·2	48·2	34	177	64
	8·5	12·0	31·6	26·2	6·3	50·2	32	191	63
	8·9	n. r.	31·9	28·4	n. r.	52·2	31	n. r.	61
April 29. Rain, 9 A.M., 0·58 April 27–28; 0·52 April 29. Small. Nit. Manure sown Feb. 23, 1882 (except Plot 15, Oct. 25, 1881).									
2 P.M.	2·1	3·7	1·1	26·0	0·5	9·0	8	740	12
4 P.M.	1·5	7·5	1·5	29·7	2·1	11·0	5	357	14
6 P.M.	1·5	8·5	1·6	30·2	1·6	12·6	5	531	13
1882. May 6. Rain, 9 A.M., 0·84 May 5. Small, had been freer.									
6 A.M.	0·6	5·3	1·3	30·0	2·0	11·5	2	265	11
9 A.M.	0·6	6·6	1·9	30·7	1·9	12·4	2	347	15
12 Noon.	0·6	n. r.	n. r.	29·6	n. r.	n. r.	2	n. r.	n. r.

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DETERMINATIONS OF NITROGEN IN THE SOILS

OF SOME OF THE

EXPERIMENTAL FIELDS AT ROTHAMSTED,

AND THE

BEARING OF THE RESULTS ON THE QUESTION OF THE SOURCES OF THE NITROGEN OF OUR CROPS.

BY

SIR JOHN BENNET LAWES, BART., LL.D., F.R.S., F.C.S.,

AND

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;ir JOHN BENNET LAWES, Bart., LL.D., F.R.S., F.C.S., and JOSEPH HENRY GILBERT, Ph.D., F.R.S., F.C.S., F.L.S.

INTRODUCTION.

just about a century since the question of the sources of the gen of vegetation became a subject of experimental inquiry, and of conflicting opinion. It is nearly half a century since Bous-ult was led by a study of the chemistry of agricultural produc-to see the importance of determining the sources of the nitrogen dically available to vegetation over a given area of land. Some-later the Rothamsted experiments, now in their fortieth year, commenced, and in their progress many facts have been elicited ng upon the same subject. Still, almost from the date of Bous-ult's first investigations, the question has been one of contro-, and at the present time very conflicting views are entertained cting it.

'or ourselves, we have pointed out how entirely inadequate is the nt of combined nitrogen coming down in the measureable ous deposits from the atmosphere to supply the nitrogen of the tation of a given area. Other possible supplies of combined gen from the atmosphere have also been considered, and pro-ced inadequate. Again, the question whether or not plants nilate the free or uncombined nitrogen of the atmosphere has the subject of laborious experimental inquiry, and also of critical ssion, at Rothamsted. Finally, the question whether the stores e soil itself are an important source of the nitrogen of our crops frequently been considered.

t may at the outset be frankly admitted that so long as the facts roduction alone are studied, without knowledge of, or reference he changes in the stock of the nitrogen in the soil, it would seem ntial to assume that a large proportion of the nitrogen of crops

growing without any direct supply of it by manure, must be derived, in some way or other, from atmospheric sources.

The assumption which is most in favour with some prominent writers is, that whilst some plants derive most or all of their nitrogen from the stores of the soil itself, or from manure applied to it, others derive a large proportion from the free nitrogen of the atmosphere. We, on the other hand, whilst freely admitting that the facts of production are not conclusively explained thereby, have maintained that such collateral evidence as the determinations of nitrogen in our soils afford, is in favour of the supposition that the soil may be the source of the otherwise unexplained supply of nitrogen. This latter conclusion we have frequently stated in general terms; but we have not hitherto published the numerical results upon which it is based. Fairly enough, it has been objected that such an important conclusion cannot be accepted without the numerical evidence to support it. Further, erroneously interpreting our statements, calculations have been made to show that it is quite beyond the reach of present methods of determination of nitrogen in soils to afford results justifying the conclusions we have drawn.

Since this subject of the sources of the nitrogen of our crops has been much discussed in America, it has been thought that it would not be inappropriate to answer the challenge by bringing forward some of the numerical evidence we have accumulated before this meeting of the American Association for the Advancement of Science, and to do this is the object of the present communication.

Before calling attention to the special results in question, it will be necessary, in order to convey a clear idea of the problem to be solved, to recapitulate some of the important facts which have been established as to the amount of nitrogen yielded over a given area by different crops.

In his original inquiries, Boussingault estimated the amounts of nitrogen supplied by manure, and removed in the crops, in ordinary agricultural practice. This mode of estimate is also the one generally adopted by others, and we have ourselves not neglected it. But it is obvious that the results of experiments in which different crops have been grown for very many years in succession on the same land, both separately and in an actual course of rotation, and both without nitrogenous manure and with known quantities of such manure, must afford very important data as to the amounts of nitrogen available to vegetation, from soil and atmosphere, over a given area. The Rothamsted field experiments are pre-eminently adapted to provide such data. Thus, wheat has now been grown for thirty-nine years

in succession on the same land; barley for thirty-one years; wheat in alternation with fallow thirty-one years; beans for nearly thirty years; clover for many years; turnips, sugar-beet, or mangels, nearly forty years; whilst experiments on the mixed herbage of grass land have been continued for twenty-seven years, and on an actual course of rotation for thirty-five years. We have, from time to time, published what we may call the nitrogen statistics of the crops so grown; and we have compared these facts of production with what is known of the sources of nitrogen available to the crops.

Yield of Nitrogen in Different Crops.

The following table (I) shows the yield of nitrogen per acre per annum, in wheat, barley, root-crops, beans, clover, and in ordinary rotation, in each case without any nitrogenous manure. It will be observed that only in the case of the root-crops is the record brought down to a later date than 1875. Independently of the fact that the requisite nitrogen determinations are not yet completed for the subsequent period, it has been decided that, owing to the number of very exceptionally unfavourable seasons for corn crops which have occurred since 1875, it would be fallacious to bring the results for those crops in the later seasons as illustrating the falling off of yield due to soil exhaustion.

Table I.

Yield of Nitrogen per acre per annum in various Crops grown at Rothamsted, without Nitrogenous Manure.

Crops, &c.	Condition of Manuring, &c.	Duration of Experiment.	Average Nitrogen per Acre per annum.
			lbs.
Wheat	Unmanured	8 years, 1844–'51	25·2
		12 years, 1852–'63	22·6
		12 years, 1864–'75	15·9
		24 years, 1852–'75	19·3
		32 years, 1844–'75	20·7
	Complex mineral manure	12 years, 1852–'63	27·0
		12 years, 1864–'75	17·2
		24 years, 1852–'75	22·1
Barley	Unmanured	12 years, 1852–'63	22·0
		12 years, 1864–'75	14·6
		24 years, 1852–'75	18·3
	Complex mineral manure	12 years, 1852–'63	26·0
		12 years, 1864–'75	18·8
		24 years, 1852–'75	22·4
Root-crops	Complex mineral manure: Turnips	8 years, 1845–'52	42·0
	(Barley)	3 years, 1853–'55	(24·3)
	Turnips	15 years, 1856–'70*	18·5
	Sugar beet	5 years, 1871–'75	13·1
	Mangels	5 years, 1876–'80	15·5
	Total	36 years, 1845–'80	25·2
Beans	Unmanured	12 years, 1847–'58	48·1
		12 years, 1859–'70†	14·6
		24 years, 1847–'70	31·3
	Complex mineral manure	12 years, 1847–'58	61·5
		12 years, 1859–'70†	29·5
		24 years, 1847–'70	45·5
Clover	Unmanured	22 years, 1849–'70‡	30·5
	Complex mineral manure	22 years, 1849–'70‡	39·8
Barley	Unmanured	1 year, 1873	37·3
Clover		1 year, 1873	151·3
Barley	Unmanured: After barley	1 year, 1874	39·1
	After clover	1 year, 1874	69·4
	Barley after clover more than after barley	—	30·3
Rotation 7 courses: 1. Turnips 2. Barley 3. Clover or beans 4. Wheat	Unmanured	28 years, 1848–'75	36·8
	Superphosphate	28 years, 1847–'75	45·2

* Thirteen years' crop, two years failed.
† Nine years' beans, one year wheat, two years' fallow.
‡ Six years' clover, one year wheat, three years' barley, twelve years' fallow.

Yield of Nitrogen in Wheat and Barley.

The first series of results relates to the yield of nitrogen in wheat grown thirty-two years in succession on the same land without manure. It is seen that, over the first eight years, the yield was 25·2 pounds of nitrogen per acre per annum, over the next twelve years 22·6 pounds, and over the last twelve of the thirty-two years only 15·9. There has thus been a considerable reduction in the annual yield of nitrogen over each succeeding period; and for the third period of twelve years the average is less than two-thirds as much as for the first period of eight years.

Excluding the first eight years of the growth of wheat, the average annual yield of nitrogen over the next twenty-four years was 19·3 pounds per acre per annum; and the table shows that over the same twenty-four years, barley without manure yielded 18·3 pounds; and whilst with the wheat the decline in yield was from 22·6 pounds over the first twelve of the twenty-four years to 15·9 over the second twelve, it was with the barley from 22·0 to 14·6 pounds, or almost in the same proportion.

It might be objected that here the evidence is not conclusive that the falling off is due to the gradual reduction in the amount of nitrogen annually available from the soil. But the results with the two crops, where there is a liberal supply of mineral constituents every year, exclude the supposition that the decline is due to the exhaustion of mineral constituents. Thus, over the same twenty-four years, with a complex mineral manure, such as is very effective in conjunction with artificial supply of nitrogen to the soil, the yield of nitrogen in the wheat falls off from 27·0 pounds per acre per annum over the first twelve years, to 17·2 pounds over the second twelve years; and in the barley, over the same two periods, it declines from 26·0 to 18·8 pounds.

The similarity in the actual yield, and in the rate of decline of yield, of nitrogen over the same periods in these two closely allied crops, though growing in different fields, and with somewhat different previous manurial history, is very striking. The slightly higher yield in both cases with than without the mineral manure is doubtless due to more complete utilisation of the previous accumulations within the soil, and not to increased assimilation from atmospheric sources.

Yield of Nitrogen in Root-crops.

We now come to the yield of nitrogen by plants of other natural families, and the first of such results relate to the so-called "root-

crops"—turnips of the natural order Cruciferæ, and sugar-beet, and mangel-wurzel of the order Chenopodiaceæ. The table records the results for thirty-six years in succession, 1845–1880; but it should be stated that during three of those years barley was interposed without any manure, in order, as far as possible, to equalise the condition of the land before re-arranging the manuring; and during two other years the turnips failed, and there was no crop. It should be further explained that, without manure of any kind, root-crops, after a few years, give scarcely any produce at all, and hence the results selected, and recorded in the table, are those obtained by the use of mineral manures, but without any supply of nitrogen.

During the first eight years (four years Norfolk whites and four years Swedes), the turnips gave an average of 42 pounds of nitrogen per acre per annum, or very much more than either of the cereal crops. During the next three years barley (without manure) yielded 24·3 pounds, or even somewhat less than the yield in wheat or barley with mineral manures in the earlier years of their continuous growth. During the next fifteen years (thirteen with Swedish turnips and two without any crop), the yield was reduced to 18·5 pounds; during the next five years, with sugar-beet, to 13·1 pounds; and during the last five years, to 1880 inclusive (with mangel-wurzel), to 15·4 pounds. Lastly, over the whole thirty-six years, the average annual yield of nitrogen was 25·2 pounds.

Here, then, compared with wheat or barley, we have with the root-crops, the growth of which extends much further into the autumn months, a much higher annual yield of nitrogen in the earlier years, and with this a much more rapid rate of decline subsequently, the annual yield over the last ten years being only about one-third as much as over the first eight years; whilst the yield in the later years is actually less than in either wheat or barley with the same complex mineral manure. Here, again, the marked decline in the yield of nitrogen, with liberal mineral manuring, points to a deficiency in the available supply of nitrogen itself as the cause of the deficient assimilation of it by the crop.

It may here be observed, that those who maintain that the atmosphere is an important source of the nitrogen of our crops assume that the root-crops, if provided with a small quantity of nitrogenous manure to favour the early development of the plant, will obtain the remainder from the atmosphere. How far this is the case may be illustrated by the following results, which are the average of five years' successive growth of mangel-wurzel on the same plots, and in each case with the same manure year after year.

TABLE II.

Average produce of Mangel-wurzel five years, 1876—1880.

	Roots.		Leaves.	
	Tons.	Cwt.	Tons.	Cwt.
1. Superphosphate of lime, and sulphate potassium ..	4	10	1	0
2. As 1, and 36¼ lbs. ammonium salts (= 7·8 lbs. N) .	6	0	1	6
3. As 1, and 400 lbs. ammonium salts (= 86 lbs. N) .	14	0	2	16

Thus, the annual application of about 7·8 pounds of nitrogen, as ammonium salts, has increased the crop of roots by only 30 cwts. per acre per annum; and the increased yield of nitrogen in the crop was even somewhat less than the amount supplied in the manure. An application of 86 pounds of nitrogen has, however, increased the crop by 160 cwts. more. It is obvious from these facts, that the small application of nitrogen did not enable the plant to take up any from atmospheric sources, and that it required further direct supply of nitrogen to obtain further increase of crop. These results obviously afford confirmation of the view that it was a reduction of the available supply of nitrogen within the soil that was the cause of the decline in the annual yield of the crop, and of the amount of nitrogen contained in it.

Yield of Nitrogen in Leguminous Crops.

We next come to the consideration of the yield of nitrogen in crops of the leguminous family, when these are grown separately, year after year, on the same land. Plants of this family are said to rely almost exclusively on atmospheric sources for their nitrogen.

Table I shows that, without manure, beans gave over the first twelve years an annual yield of 48·1 pounds of nitrogen, but over the second twelve only 14·6 pounds. Over the first period, therefore, the yield was about twice as much as in either wheat or barley, and more even than with the roots. But with this greater yield in the earlier years, the reduction is proportionally much greater over the second period; the yield then coming down to less than one-third, and to much the same as in the later periods with the other crops. Over the whole period of twenty-four years, however, there was an annual yield of 31·3 pounds of nitrogen, or more than one and a half time as much as in either wheat or barley, and more than in the roots.

It was seen that in the case of the cereal crops the mixed mineral

manure increased the yield of nitrogen but little. Not so in the case of the leguminous crop, beans. During the first twelve years, the complex mineral manure (containing a large amount of potash) yielded 61·5 pounds of nitrogen per acre per annum, against 48·1 pounds without manure. During the next twelve years, the mineral manure gave 29·5 pounds, against only 14·6 pounds without manure. During the whole period of twenty-four years, the potash manure yielded 45·5 pounds of nitrogen per acre per annum, against 31·3 pounds without manure. Lastly, with the mixed mineral manure beans have yielded over a period of twenty-four years more than twice as much nitrogen per acre as either wheat or barley.

But notwithstanding that the beans have for a long series of years yielded so very much more nitrogen over a given area than either of the gramineous crops, and much more also than the root-crops, the significant fact cannot fail to be observed that this crop of the leguminous family, which is supposed to rely almost exclusively on the atmosphere for its nitrogen, has declined in yield as strikingly as the other crops, even when grown by a complex mineral manure, containing a large amount of potash. Why should this be so if the supply of nitrogen is from the atmosphere and not from the soil?

The results next recorded relate to red clover, and the period of experiment was twenty-two years. It is well known that on most soils a good crop of clover cannot be relied upon oftener than once in about eight years, and on many soils not so frequently. It will not excite surprise, therefore, that in the course of the twenty-two years of experiment, in only six was any crop of clover obtained, and in some of those only poor ones. Indeed, the plant failed nine times out of ten during the winter and spring succeeding the sowing of the seed. In one year a crop of wheat, and in three years barley, was taken instead; whilst in the remaining twelve years the land was left fallow after the failure of the clover. Still the annual yield of nitrogen over the twenty-two years was 30·5 pounds without any manure, and 39·8 pounds by a complex mineral manure containing potash. Unfavourable as is this result in an agricultural point of view, it is still seen that the interpolation of this leguminous crop has greatly increased the yield of nitrogen compared with that in either wheat or barley grown continuously; and here again, as with beans, a potash manure has considerably increased the yield.

The next experiment affords a still more striking illustration of the large amount of nitrogen that may be taken up in a clover crop; and it further illustrates the fact, well known in agriculture, that the removal of this highly nitrogenous [illegible]

possible preparations for the growth of a cereal crop, which characteristically requires nitrogenous manuring. A field which had grown six corn crops in succession, by artificial manures alone, was then divided, and (in 1873) on one half barley, and on the other half clover, was grown. The barley yielded 37·3 pounds of nitrogen per acre; but the three cuttings of clover yielded 151·3 pounds. In the next year (1874) barley was grown on both portions of the field. Where barley had previously been grown, and had yielded 37·3 pounds of nitrogen per acre, it now yielded 39·1 pounds; but where the clover had previously been grown, and had yielded 151·3 pounds of nitrogen, the barley succeeding it gave 69·4 pounds, or 30·3 pounds more nitrogen after the removal of 151·3 pounds in clover than after the removal of only 37·3 pounds in barley. It will be seen further on that this result was not in any way accidental.

Yield of Nitrogen by a Rotation of Crops.

The last results recorded in the table relate to the yield of nitrogen in an ordinary four-course rotation of—turnips, barley, clover or beans, and wheat. The average yield per annum is given for seven courses, or for a period of twenty-eight years; in one case without any manure during the whole of that time, and in the other with superphosphate of lime alone, applied once every four years, that is, for the turnips commencing each course.

Here, with a turnip crop, and a leguminous crop, interpolated with two cereal crops, we have, without manure of any kind, an average of 36·8 pounds of nitrogen per acre per annum, or very much more than was obtained in either of the cereal crops grown consecutively. With superphosphate of lime alone, which much increased the yield of nitrogen in the turnips, reduced it in the succeeding barley, increased it greatly in the leguminous crops, and slightly in the wheat succeeding them, the average annual yield of nitrogen is increased to 45·2 pounds, or to about double that obtained in either wheat or barley grown consecutively by a complete mineral manure. On this point it may be further remarked that in adjoining experiments, in which, instead of a leguminous crop, the land was fallowed in the third year of each course, the total yield of nitrogen in the rotation was very much less. In other words, the removal of the most highly nitrogenous crops of the rotation—clover or beans—was succeeded by a growth of wheat, and an assimilation of nitrogen by it, almost as great as when it succeeded a year of fallow; that is, a period of some accumulation by rain, &c., and of no removal by crops.

Yield of Nitrogen in the Mixed Herbage of Grass Land.

Another illustration of the amounts of nitrogen removed from a given area of land by different descriptions of crop will be found in Table III, which shows the results obtained when plants of the gramineous, the leguminous, and other families, are grown together, in the mixed herbage of grass land.

TABLE III.

Yield of Nitrogen on the Mixed Herbage of Permanent Grass Land at Rothamsted.

Plots.	Conditions of Manuring.	Average Produce per acre per annum, 20 years, 1856-1875, according to mean per cent., at six periods, 1862, '67, '71, '72, '74, '75.			Average Nitrogen per Acre per annum.		
		Gramineæ.	Leguminosæ.	Other Orders	Ten years 1856-1865.	Ten years 1866-1875.	Twenty years 1856-1875
		lbs.	lbs	lbs.	lbs.	lbs.	lbs.
3	Unmanured	1635	219	529	35·1	30·9	33·0
4-1	Superphosphate*	1671	149	673	35·7	31·5	33·6
6	Complex Min. Man.†	2442	296	639	54·4	38·1	46·3
7	Complex Min. Man.‡	2579	806	573	55·2	56·0	55·6

Before referring to the figures, attention should be called to the fact that gramineous crops grown separately on arable land, such as wheat, barley, or oats, contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area. Yet nitrogenous manures have generally a very striking effect in increasing the growth of such crops. The highly nitrogenous leguminous crops, on the other hand, such as beans and clover, yield, as has been seen, very much more nitrogen over a given area: yet they are by no means characteristically benefited by nitrogenous manuring, but their growth is considerably increased, and they yield considerably more nitrogen over a given area, under the influence of purely mineral manures, and especially of potash

* Mean of four separations only, namely, 1862, 1867, 1872, and 1875.

† Including potash, six years, 1856-1861; without potash, 14 years, 1862-1875.

‡ Including potash, 20 years, [illegible].

manures. Bearing these facts in mind, the results given in the table will be seen to be quite consistent.

The first three columns in the table show, approximately, how the mixed herbage was made up under the four different conditions of manuring. It will be observed that, without manure, and with superphosphate of lime alone, both the proportion and the amount of the different descriptions of herbage are much the same. Plot 8, with a complex mineral manure, including potash the first six years, but excluding it the next fourteen years, gave a considerable increase of both gramineous and leguminous herbage; whilst plot 7, with a complex mineral manure, including potash every year of the twenty, there is a still further increase of gramineous herbage, but a very much greater proportional increase of leguminous herbage.

It will be observed how much greater is the increase of gramineous produce by the application of purely mineral manures to this mixed herbage than in the case of gramineous crops grown separately. It is a question how far this is due to the mineral manures enabling the grasses to form much more stem and seed, that is, the better to mature, which in fact they do; how far to their favouring more active nitrification in the more highly nitrogenous permanent mixed herbage soil; or how far to an increased amount of combined nitrogen in a condition available for the grasses in the upper layers of the soil, as the result of the increased growth of the Leguminosæ in the first instance, induced by the potash manure, as in the case of the alternation of clover and barley, and as in the actual course of rotation?

To turn to the yield of nitrogen on the different plots of the mixed herbage, it will be seen that the amounts are almost identical without manure, and with superphosphate of lime alone, about 33 pounds per acre per annum. On plot 8, where a complex mineral manure, including potash six years, but excluding potash fourteen years, was employed, the amount is raised to 46·3 pounds; and on plot 7, which received the mixed mineral manure, including potash every year of the twenty, the yield is 55·6 pounds per acre per annum. Further, without manure, and with superphosphate of lime alone, there was a decline in the yield of nitrogen in the later, compared with the earlier years. With the mineral manure, including potash in the first six years only, there was a much more marked decline. With the mineral manure, including potash every year, there was, on the other hand, even a slight tendency to an increased yield of nitrogen in the later years.

Yield of Nitrogen in Melilotus Leucantha.

One more striking illustration of high yield of nitrogen by a plant of the leguminous family, this time on soil which had not received any nitrogenous manure for nearly thirty years, must be given. In 1878, the land upon which attempts had been made to grow red clover in frequent succession since 1849, was devoted to experiments with fourteen different descriptions of leguminous plants: so that the present season, 1882, is the fifth year of the experiments. The object was to ascertain whether, among a selection of plants, all of the leguminous family, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen as well as other constituents, than others; all being supplied with the same descriptions and quantities of manuring substances, applied to the surface soil. Further, whether the success in some cases and the failure in others, would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of red clover in particular, when it is grown too frequently on the same land. Fourteen different descriptions of plants were selected, and, after two or three immaterial changes, the list at the present time includes eight species or varieties of *Trifolium*, two of *Medicago*, *Melilotus leucantha*, *Lotus corniculatus*, *Vicia sativa*, and *Onobrychis sativa*.

Of the numerous species or varieties of *Trifolium*, all gave but meagre produce, excepting *T. incarnatum*. The *Lotus corniculatus* also gave very small produce. The two species of *Medicago*, the black *Medick*, and the purple *Medick* or Lucerne, and the *Onobrychis*, or common Sainfoin, gave much more; the *Vicia sativa* or common vetch, more still. But of all, the *Melilotus leucantha*, or Bokhara clover, has yielded the most. It is estimated that, taking the average of four years, 1878–81, it yielded about 70 pounds of nitrogen per acre per annum, on plots which have received no nitrogenous manure for more than thirty years; whilst the produce of the fifth season, 1882, is heavier than in either of the preceding years; and it is estimated to contain about 150 pounds of nitrogen. In fact, in the second, as well as in the fifth year, the *melilotus* yielded considerably more than 100 pounds of nitrogen per acre; and on the average of the five years it has yielded between 80 and 90 pounds per acre on this nitrogen-exhausted soil.

How long this very luxuriant growth, and this very high yield of nitrogen per acre, will continue, is a question of

On this point it may be observed that, in parts of the continent of Europe where some of the very free-growing and deep-rooted Leguminosæ are cultivated, it is usual to let them grow for several years, after which they cannot be repeated for twenty years or more. We shall recur to the results above quoted further on.

Summary of Yield of Nitrogen in Crops.

The foregoing facts of production, showing the yield of nitrogen in different crops grown without nitrogenous manure, generally for very many years in succession on the same land, may be briefly summed up as follows:

The average yield of nitrogen per acre per annum, was, with wheat, thirty-two years without manure, 20·7 pounds, and twenty-four years with a complex mineral manure, 22·1 pounds; with barley, twenty-four years without manure, 18·3 pounds, and twenty-four years with a complex mineral manure, 22·4 pounds; with root-crops, thirty-six years (including three of barley), with a complex mineral manure, 25·2 pounds; with beans, twenty-four years without manure, 31·3 pounds, and twenty-four years with a complex mineral manure, 45·5; with clover, six crops in twenty-two years, with one crop of wheat, three crops barley, and twelve years fallow, without manure, 30·5 pounds; with complex mineral manure, 39·8 pounds; with clover, on land which had not grown the crop for very many years, one year, 151·3 pounds; with a rotation of crops, seven courses, twenty-eight years, without manure, 36·8 pounds, and with superphosphate of lime, 45·2 pounds; with the mixed herbage of grass land, twenty years without manure, 33 pounds, and with complex mineral manure, including potash, 55·6; lastly, with Bokhara clover, five years, with mineral manure, between 80 and 90 pounds of nitrogen per acre per annum.

The root-crops yielded more nitrogen than the cereal crops, and the leguminous crops very much more still.

In all the cases of the experiments on ordinary arable land—whether with cereal crops, root-crops, leguminous crops, or a rotation of crops (excepting as yet the Bokhara clover)—*the decline in the annual yield of nitrogen, none being supplied by manure, was very great.*

Sources of the Nitrogen of Crops.

We must next consider whence comes the nitrogen of the crops, and especially whence comes the much larger amount taken up by plants of the leguminous, and some other families, than by the

Gramineæ. Lastly, what is the significance of the great decline in the yield of nitrogen in all the crops grown on arable land when none is supplied in the manure?

Combined Nitrogen in Rain, &c.

It has been assumed by some that the amount of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere is sufficient for all the requirements of annual growth. In Liebig's earlier writings he assumed the probability of a very much larger quantity of ammonia coming down in rain than he did subsequently; but even in his more recent work, "The Natural Laws of Husbandry," published in 1863, he supposes that as much as 34 pounds of nitrogen per acre may be annually available to vegetation from that source. Such an amount would, it is obvious, do much towards meeting the requirements of many of the crops the nitrogen statistics of which have been given.

The earliest considerable series of determinations of the amount of ammonia coming down in rain in the open country were by Boussingault, in Alsace. He gives the amount of ammonia per million of rain-water in each fall for a period of between five and six months, May–October, 1852; but he does not calculate the amount so coming down over a given area of land. His average amount per million was, however, somewhat less than that found at Rothamsted in 1853 and 1854, and found by Mr. Way in Rothamsted rain-water collected in 1855 and 1856; which, calculated according to the rain-fall of the periods, give the following amounts of nitrogen so coming down per acre. The amounts of nitrogen as nitric acid, as determined by Mr. Way, and the amount of total combined nitrogen as ammonia and nitric acid together, are also given.

TABLE IV.

Nitrogen, as Ammonia and Nitric Acid, in the Rainfall of Three Years, at Rothamsted, in Pounds per Acre.

Years.	Rainfall.	Nitrogen per Acre, as—		
		Ammonia.	Nitric Acid	Total Nitrogen.
	Inches.	lbs.	lbs.	lbs.
1853–'54	29·014	5·20	(0·74)	5·94
1855..................	29·166	5·82	0·72	6·58
1856..................	27·215	7·28	0·76	8·[illegible]
Mean	28·465	6·10	0·74	[illegible]

It will be seen that, according to these results, an average of 6·84 pounds was contributed per acre per annum in the rain in the form of ammonia and nitric acid. More recently, however, Dr. Frankland has determined the amount of ammonia and nitric acid in numerous samples of rain and snow water, dew, hoar-frost, &c., collected at Rothamsted from April, 1869, to May, 1870, inclusive : and the average amount of ammonia per million of water found by him is considerably lower than the earlier determinations show. More recently still the ammonia has been determined in the Rothamsted laboratory, in the rain of each day separately (if any), for a period of six months, July–December, 1881 ; also in the proportionally mixed rain for each month, for a period of thirteen months, June, 1881, to June, 1882. The average proportion of ammonia in these most recent determinations accords with the results of Dr. Frankland, and points to a smaller amount of total combined nitrogen supplied per acre in the average annual rainfall at Rothamsted than that recorded in the table ; probably, indeed, to not more than four or five pounds of total combined nitrogen per acre per annum.

Dr. R. Angus Smith, in his work entitled "Air and Rain, the Beginnings of a Chemical Climatology," 1872, gives the results of numerous analyses of rain-water collected both in country and town districts in the United Kingdom. The amounts of ammonia and nitric acid in the rain vary exceedingly, according to locality ; but the amounts in the rain of country places accord generally with those found in the Rothamsted rainfall.

The following table summarises the results of numerous determinations made at various stations on the continent of Europe, in each case extending over a whole year :—

TABLE V.

Nitrogen as Ammonia and Nitric Acid in the Rain of various Localities in Europe.

[Quantities in Pounds per Acre per Annum.]

Localities.	Years.	Rainfall.	Nitrogen as— Ammonia.	Nitric Acid.	Total.
		Inches.	lbs.	lbs.	lbs.
Kuschen	1864–'65	11·85	1·44	0·42	1·86
Kuschen	1865–'66	17·70	1·83	0·67	2·50
Insterburg	1864–'65	27·55	3·55	1·94	5·49
Insterburg	1865–'66	23·79	4·14	2·67	6·81
Dahme	1865	17·09	5·50	1·16	6·66
Regenwalde	1864–'65	23·48	10·82	4·27	15·09
Regenwalde	1865–'66	19·31	8·27	2·11	10·38
Regenwalde	1866–'67	25·37	13·20	3·24	16·44
Ida - Marienhütte; mean six years	1865–'70	22·65	..	..	9·92
Proskaw	1864–'65	17·81	13·58	7·33	20·91
Florence	1870	36·55	9·71	3·65	13·36
Florence	1871	42·48	7·78	2·11	9·89
Florence	1872	50·82	9·50	3·01	12·51
Vallombrosa	1872	79·83	7·65	2·73	10·38
Montsouris, Paris	1877–'78	23·62	10·25	1·29	11·54
Montsouris, Paris	1878–'79	25·79	7·05	4·11	11·16
Montsouris, Paris	1879–'80	15·70	4·83	5·69	10·52
Mean, 22 years	..	27·03	..	..	10·23

It is seen that the numerous very widely varying determinations, some made in the vicinity of towns and some in the open country, give a mean of 10·23 pounds of combined nitrogen annually supplied per acre by rain with a mean rainfall of 27·03 inches. Making all allowance for far inland open country positions on the one hand, and for proximity to towns on the other, the very small amounts of combined nitrogen so supplied per acre in some of the cases, and the comparatively large quantities in others, seem difficult to explain, or to reconcile, either with one another or with the results of Boussingault and of Rothamsted. When, however, the comparatively limited and uniform total amounts recorded for Montsouris, within the walls of Paris, are considered, 11·54 pounds, 11·16 pounds, and 10·52 pounds per acre per annum, it will not excite surprise that we should estimate the amount of combined nitrogen coming down in the measured aqueous deposits

rom the atmosphere at probably not more than, if as much as, pounds per acre per annum in the open country at Rothamsted.

With records of the amounts of combined nitrogen contributed to given area in rain, we come to an end of all quantitative evidence s to the amount of combined nitrogen available to the vegetation of given area from atmospheric sources. It will be seen how entirely iadequate is the amount probably so available to supply the quantities yielded in different crops grown without nitrogenous manure, as corded in Tables I and III (pp. 8 and 14).

It is true that the minor aqueous deposits from the atmosphere are uch richer in combined nitrogen than rain, and there can be no oubt that there would be more deposited within the pores of a given rea of soil than on an equal area of the non-porous even surface of a ain-gauge. How much, however, of this might be available beyond iat determined in the collected aqueous deposits, existing evidence oes not afford the means of estimating with certainty.

Other Supposed Sources of Combined Nitrogen.

Further, it has been argued that, in the last stages of the decomosition of organic matter in the soil, hydrogen is evolved, and that his nascent hydrogen combines with the free nitrogen of the atmophere, and so forms ammonia. Again, it has been suggested that zone may be evolved in the oxidation of organic matter in the oil, and that, uniting with free nitrogen, nitric acid would be proluced.

We have discussed these various possible supplies of combined itrogen to the soil from atmospheric sources on more than one occaion; and we have given our reasons for concluding that none of them an be taken as accounting for the facts of growth. Incidentally, some vidence will be given further on, confirming the conclusion that any uch supplies are limited and inadequate.

But, if the supplies from the atmosphere to the soil itself are nadequate, how about the direct supplies from the atmosphere to the lant?

One view which has been advocated is, that broad-leaved plants iave the power of taking up combined nitrogen from the atmosphere, n a manner, or in a degree, not possessed by the narrow-leaved ramineous plants. The only experiments that we are aware of, made o determine whether plants can take up nitrogen by their leaves rom ammonia supplied to them in the ambient atmosphere, are those f Adolph Mayer in Germany, and of Schlösing in France. Both

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Do Plants Assimila

The question still remains to con
the free nitrogen of the atmosphe
do so in a much greater degree th
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This question has been the subje
inquiry, since the time that Boussi
year 1837; and more than twenty ye
gated at Rothamsted.

We will here give a summary of
have been published in reference to
the free nitrogen of the atmosphere
want of space, to the three most con
which have been undertaken relating

Though not the first in point
experiments of M. G. ...

Table VI.

Results of M. G. Ville's *Experiments, to determine whether Plants assimilate free Nitrogen.*

Plants.	Nitrogen, grams. In Seed, and Air; and Manure, if any.	In Products. *	Gain or Loss.	Nitrogen in Products to 1 Supplied.
1849: *Current of unwashed air supplying* 0·001 *gram N. as Ammonia.**				
Cress	0·0260	0·1470	0·1210	5·6
Large Lupins	0·0640	0·0640	0·0000	1·0
Small Lupins	0·0640	0·0470	−0·0170	0·7
	0·1550	0·2580	0·1030	1·7
1850: *Current of unwashed air supplying* 0·0017 *gram N. as Ammonia.**				
Colza (plants)	0·0260	1·0700	1·0440	41·1
Wheat	0·0160	0·0310	0·0150	1·9
Rye	0·0130	0·0370	0·0240	2·8
Maize	0·0290	0·1280	0·0990	4·4
	0·0857	1·2660	1·1803	14·8
1851: *Current of washed air.**				
Sunflower	0·0050	0·1570	0·1520	31·4
Tobacco................	0·0040	0·1750	0·1710	43·7
Tobacco................	0·0040	0·1620	0·1580	40·5
1852: *Current of washed air.**				
Autumn Colza..........	0·0480	0·2260	0·1780	4·7
Spring Wheat	0·0290	0·0650	0·0360	2·2
Sunflower	0·0160	0·4080	0·3920	25·5
Summer Colza..........	0·1730	0·5950	0·4220	3·4
Summer Colza	0·1050	0·7010	0·5960	6·7
1854: *Current of washed air (under superintendence of a Commission).*				
Cress	0·0099	0·0097	−0·0002	1·0
Cress	0·0038	0·0530	0·0492	13·9
Cress	0·0039	0·0110	0·0071	2·8

* **Recherches Expérimentales sur la Végétation, par M. Georges Ville, Paris, 1853.**

* In Plants only

TABLE VI.—*continued.*

Plants.	Nitrogen, grams. In Seed, and Air; and Manure, if any.	Nitrogen, grams. In Products.	Nitrogen, grams. Gain or Loss.	Nitrogen in Products to 1 Supplied.
1854: *Current of washed air (closed, superintended by a Commission).**				
Cress	0·0063	0·0350‡	0·0287	5·6
1855 *and* 1856: *In pure air, with* 0·5 *gram Nitre* = 0·069 *Nitrogen.*†				
Colza	0·0700	0·0700‡	0·0000	1·0
Colza	0·0700	0·0660‡	−0·0040	0·9
Colza	0·0700	0·0680‡	−0·0020	1·0
1855 *and* 1856: *In free air, with* 1 *gram Nitre* = 0·138 *Nitrogen.*†				
Colza	0·1400	0·1970‡	0·0570	1·41
Colza	0·1400	0·3740‡	0·2340	2·67
Colza	0·1400	0·2160‡	0·0760	1·54
Colza	0·1400	0·2500‡	0·1100	1·79
1856: *In free air, with* 0·792 *gram Nitre* = 0·110 *Nitrogen.*†				
Wheat	0·1260	0·2180‡	0·0920	1·7
Wheat	0·1260	0·2240‡	0·0980	1·8
1855: *In free air, with* 1·72 *grams Nitre* = 0·238 *Nitrogen.*†				
Wheat	0·2590	0·3080‡	0·0490	1·2
1856: *In free air, with* 1·765 *grams Nitre* = 0·244 *Nitrogen.*†				
Wheat	0·2650	0·2170‡	−0·0480	0·8
Wheat	0·2650	0·3500‡	+0·0850	1·3

These results, as well as those of others, we have fully discussed elsewhere (*Phil. Trans.*, 1859, and *Jour. Chem. Soc.*, vol. xvi, 1863), and we can only very briefly refer to them in this place.

The column of actual gain or loss shows in one case, with colza, a gain of more than 1 gram nitrogen; and the amount in the products is more than forty-one times as much as that supplied as combined

* Compt. rend., 1855.

† Recherches Expérimentales sur la Végétation, 1857.

‡ In plants only.

nitrogen in the seed and air. The results with wheat, rye, or maize, showed very much less of both actual and proportional gain. Experiments with sunflower showed in one case thirty-fold, and with tobacco in two cases more than forty-fold, as much in the products as was supplied. It will be observed, however, that upon the whole M. G. Ville's later experiments showed considerably less both actual and proportional gain than his earlier ones.

M. G. Ville in some cases attributed the gain to the large leaf surface. In explanation of the assimilation of free nitrogen by plants, he calls attention to the fact that nascent hydrogen is said to give ammonia, and nascent oxygen nitric acid, with free nitrogen, and he asks: Why should not the nitrogen in the juices of the plant combine with the nascent carbon and oxygen in the leaves? He refers to the supposition of M. De Luca, that the nitrogen of the air combines with the nascent oxygen given off by the leaves of plants, and to the fact that the juice of some plants (mushrooms) has been observed to ozonise the oxygen of the air, and he asks: Is it not probable, then, that the nitrogen dissolved in the juices will submit to the action of the ozonised oxygen with which it is mixed, when we bear in mind that the juices contain alkalies, and penetrate tissues, the porosity of which exceeds that of spongy platinum?

The following table (VII) summarises the results of M. Boussingault. His experiments on the subject commenced in 1837, and were continued at intervals up to 1858. The conditions of each set of experiments as to soil, air, or application of manurial substances, are given in the table.

TABLE VII.

Results of M. BOUSSINGAULT'S *Experiments to determine whether Plants assimilate free Nitrogen.*

Plants.	Nitrogen, grams.			Nitrogen in Products to 1 Supplied.
	In Seed, or Plants; and Manure, if any.	In Products. *	Gain or Loss.	
1837: *Burnt soil, distilled water, free air, in closed summer-house.**				
Trefoil	0·1100	0·1200	+0·0100	1·09
Trefoil	0·1140	0·1560	+0·0420	1·37
Wheat	0·0430	0·0400	−0·0030	0·93
Wheat	0·0570	0·0600	+0·0030	1·05

* Ann. Ch. Phys. [2], lxvii. (1838).

*In Plants only

TABLE VII.—*continued.*

Plants.	Nitrogen, grams. In Seed, or Plants; and Manure, if any.	In Products. *	Gain or Loss.	Nitrogen in Products to 1 Supplied.
1838: *Conditions as in 1837.**				
Peas	0·0460	0·1010	+0·0550	2·20
Trefoil (Plants)	0·0330	0·0560	+0·0230	1·70
Oats (Plants)	0·0590	0·0530	−0·0060	0·90
1851 *and* '52: *Washed and ignited pumice with ashes, distilled water, limited air, under glass shade, with Carbonic Acid.*†				
Haricot, 1851	0·0349	0·0340	−0·0009	0·97
Oats, 1851	0·0078	0·0067	−0·0011	0·86
Haricot, 1852	0·0210	0·0189	−0·0021	0·90
Haricot, 1852	0·0245	0·0226	−0·0019	0·92
Oats, 1852	0·0031	0·0030	−0·0001	0·97
1853: *Prepared pumice, or burnt brick, with ashes distilled water, limited air, in glass globe, with Carbonic Acid.*†				
White Lupin	0·0480	0·0483	+0·0003	1·01
White Lupin	0·1282	0·1246	−0·0036	0·97
White Lupin	0·0349	0·0339	−0·0010	0·97
White Lupin	0·0200	0·0204	+0·0004	1·02
White Lupin	0·0399	0·0397	−0·0002	1·00
Dwarf Haricot	0·0354	0·0360	+0·0006	1·02
Dwarf Haricot	0·0298	0·0277	−0·0021	0·93
Garden Cress	0·0013	0·0013	0·0000	1·00
White Lupin	0·1827	0·1697	−0·0130	0·93
1854: *Prepared pumice with ashes, distilled water, current of washed air, and Carbonic Acid, in glazed case.*‡				
Lupin	0·0196	0·0187	−0·0009	0·95
Dwarf Haricot	0·0322	0·0325	+0·0003	1·01
Dwarf Haricot	0·0335	0·0341	+0·0006	1·02
Dwarf Haricot	0·0339	0·0329	−0·0010	0·97
Dwarf Haricot	0·0676	0·0666	−0·0010	0·99
Lupin	0·0180	0·0334 (both Lupins together)	−0·0021	0·94
Lupin	0·0175			
Cress	0·0046	0·0052	+0·0006	1·13

* Ann. Ch. Phys. [2], lxix. (1838).
† Ann. Ch. Phys. [3], xli. (1854).
‡ Ann. Ch. Phys., Sér. [3], xliii. (1855).

* In the case of the 1838 experiments the nitrogen in "Products" seems to have included only that in the [illegible] the other cases that in plants, and soil, or plants

TABLE VII.—*continued.*

Plants.	Nitrogen, grams. In Seed, or Plants; and Manure, if any.	In Products. ✗	Gain or Loss.	Nitrogen in Products to 1 Supplied.
, '52, '53, *and* '54: *Prepared soil, or pumice with ashes; distilled water, free air, under glazed case.**				
t (dwarf), 1851....	0·0349	0·0380	+0·0031	1·09
t, 1852	0·0213	0·0238	+0·0025	1·12
t, 1853	0·0293	0·0270	−0·0023	0·92
t (dwarf), 1854....	0·0318	0·0350	+0·0032	1·10
(white), 1853	0·0214	0·0256	+0·0042	1·20
1854	0·0199	0·0229	+0·0030	1·15
1854	0·0367	0·0387	+0·0020	1·05
1852	0·0031	0·0041	+0·0010	1·32
, 1853...........	0·0064	0·0075	+0·0011	1·17
Cress, 1854......	0·0259	0·0272	+0.0013	1·05
1858: *Nitrate of Potassium as Manure.*†				
thus	0·0144‡	0·0130	−0·0014	0·90
	0·0255‡	0·0245	−0·0010	0·96

he last two columns of the table (VII) show the actual and pro- nal gain or loss of nitrogen in M. Boussingault's experiments. l be seen that in his earlier experiments, those in free air in a er house, the leguminous plants, trefoil and peas, did indicate a le gain of nitrogen: but, in all his subsequent experiments, there enerally either a slight loss, or, if a gain, it was represented in only ons, or low units, of milligrams. After 20 years of varied and ious investigation of the subject, M. Boussingault concluded that s have not the power of assimilating the free nitrogen of the atmo- e. And in a letter received from him as recently as 1876, after sing several aspects of the question, he says:—

If there is one fact perfectly demonstrated in physiology, it is of the non-assimilation of free nitrogen by plants; and I may oy plants of an inferior order, such as mycoderms and mush- s."—(Translation.)

ur own experiments on this subject were commenced in 1857, young American chemist, the late Dr. Pugh, of the Pennsylvania

* Ann. Ch. Phys., Sér. [3], xliii. (1855).

† Compt. rend., xlvii. (1858).

‡ Nitrogen in Seed and Nitrate.

the experiments of 1851, 52, 53, 54 and 58 the nit ducts included that in plants, and soil, or plas

Table VIII.

Results of Experiments made at Rothamsted to determine whether Plants assimilate free Nitrogen.

			Nitrogen, grams. In Seed, and Manure, if any.	Nitrogen, grams. In Plants, Pot, and Soil.	Nitrogen, grams. Gain or Loss.	Nitrogen in Products to 1 Supplied.
With* NO *combined Nitrogen supplied beyond that in the seed sown.						
Gramineæ	1857	Wheat....	0·0080	0·0072	−0·0008	0·90
		Barley....	0·0056	0·0072	+0·0016	1·~~24~~ 29
		Barley....	0·0056	0·0082	+0·0026	1·46
	1858	Wheat....	0·0078	0·0081	+0·0003	1·04
		Barley....	0·0057	0·0058	+0·0001	1·02
		Oats......	0·0063	0·0056	−0·0007	0·89
	1858 A*	Wheat....	0·0078	0·0078	0·0000	1·00
		Oats......	0·0064	0·0063	−0·0001	0·98
Leguminosæ ..	1857	Beans	0·0796	0·0791	−0·0005	0·99
	1858	Beans	0·0750	0·0757	+0·0007	1·01
		Peas......	0·0188	0·0167	−0·0021	0·89
Other Plants ..	1858	Buck-wheat ..	0·0200	0·0182	−0·0018	0·91
With combined Nitrogen supplied beyond that in the seed sown.						
Gramineæ	1857	Wheat....	0·0329	0·0383	+0·0054	1·16
		Wheat....	0·0329	0·0331	+0·0002	1·01
		Barley....	0·0326	0·0328	+0·0002	1·01
		Barley....	0·0268	0·0337	+0·0069	1·25
	1858	Wheat....	0·0548	0·0536	−0·0012	[illegible]
		Barley....	0·0496	0·0464	−0·0032	0·94
		Oats......	0·0312	0·0216	−0·0096	0·69
	1858 A*	Wheat....	0·0268	0·0274	+0·0006	1·02
		Barley....	0·0257	0·0242	−0·0015	0·94
		Oats	0·0260	0·0198	−0·0062	0·76
Leguminosæ ..	1858	Peas......	0·0227	0·0211	−0·0016	0·93
		Clover....	0·0712	0·0665	−0·0047	0·93
	1858 A*	Beans	0·0711	[illegible]	−0·0056	0·92
Other Plants ..	1858	Buck-wheat ..	[illegible]	0·0292	−0·0016	0·95

* These experiments were conducted in the apparatus of M. G. Ville.

State Agricultural College, devoted between two and three years to the investigation at Rothamsted. The conditions of the experiments, and the results obtained up to that date, are fully described in the papers in the *Philosophical Transactions* for 1859, and in the *Journal of the Chemical Society* in 1863, already referred to. Table VIII (p. 28) summarises the results obtained.

The upper part of the table shows the results obtained in the experiments in which no combined nitrogen was supplied beyond that contained in the seed sown. The growth was in all cases extremely restricted; and the figures show that there was in no case, whether of Gramineæ, Leguminosæ, or buckwheat, a gain indicated by as much as 3 milligrams of nitrogen. There was in most cases much less gain, or a slight loss.

The lower part of the table shows the results obtained when the plants were supplied with known quantities of combined nitrogen, in the form of a solution of ammonium sulphate applied to the soil. The actual gains or losses range a little higher in these experiments, with larger quantities of nitrogen involved; but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the Gramineæ, whilst there is in each case a loss with the Leguminosæ and the buckwheat.

It should be stated that the growth was far more healthy with the Gramineæ than with the Leguminosæ, which are even in the open field very susceptible to vicissitudes of heat and moisture, and were especially so when inclosed under glass shades. It might be objected, therefore, that the negative results with the Leguminosæ are not so conclusive as those with the Gramineæ. Nevertheless, we do not hesitate to conclude from our own experiments, as Boussingault did from his, that the evidence is strongly against the supposition that either the Gramineæ or the Leguminosæ assimilate the free nitrogen of the atmosphere.

Recapitulation.

In the foregoing *résumé* of mostly previously recorded facts, we have shown the amount of nitrogen assimilated by various crops over a given area, when grown for many years in succession on the same land without any nitrogenous manure; that is, under conditions in which the source of the nitrogen is as little as possible obscured by the influence of indefinite amounts available from manure.

It has been shown that the determined amounts of combined nitrogen annually coming down in the measured aqueous deposits from the

atmosphere in the open country are entirely insufficient to do more than supply a small proportion of the nitrogen assimilated by crops so grown.

With regard to other possible supplies of already combined nitrogen from the atmosphere to the soil, it has been pointed out that there is no direct quantitative evidence at command, and that such evidence as does exist leads to the conclusion that such supplies are very limited and inadequate.

The same may be said, even in a greater degree, of the supposed combination of the free nitrogen of the air within the soil; also of the supposition that plants take up any material proportion of their nitrogen from combined nitrogen in the atmosphere by their leaves.

Finally, it has been concluded that the balance of direct experimental evidence is decidedly against the supposition that plants assimilate the free nitrogen of the atmosphere. Indeed, the strongest argument that we know of in favour of such a supposition is that, in defect of other conclusive evidence, some such explanation of the facts of production would seem to be needed.

The Nitrogen of the Soil as a Source of the Nitrogen of Crops.

We now turn to that part of the subject which it is the special object of this communication to bring forward, namely, the determinations of nitrogen in the soils of some of the experimental fields at Rothamsted, the yield of nitrogen in which has been given, and to show the bearing of the results on the question of the sources of the nitrogen of the crops.

We have no wish or intention to ignore the difficulties inherent in the treatment of the subject from this point of view. The difficulty of the problem will at once be recognised when it is borne in mind that a difference of 0·001 in the percentage of nitrogen in the dry soil may represent a difference of from 20 to 25 pounds of nitrogen per acre in a layer of 9 inches in depth. Again, it is further to be borne in mind that, in the case of the Rothamsted arable soils with which we have to deal, the percentage of nitrogen in the first 9 inches of depth is sometimes only about 0·1, and seldom exceeds 0·14 or 0·15; that in the second 9 inches it ranges from under 0·07 to little over 0·08; in the third 9 inches from under 0·06 to about 0·07; and that in the lower depths is rather lower still.

It will be seen, therefore, that if any quantitative estimates are to be based on the percentage amounts of nitrogen determined in samples

of soil from different depths, the greatest care must be taken to insure that the samples truly represent the exact depth supposed. The mode usually adopted of taking samples of an indefinite area, perhaps not to a definite depth, and almost certainly not of uniform breadth or width to the depth taken, is obviously quite inapplicable for the purposes of any such inquiry as that here supposed.

Another difficulty is that, in the case of subsoils, with a low actual percentage of nitrogen, the variations in the amount in different samples are often proportionally great, and obviously unconnected with the special history of the plot.

Unfortunately, the few samples of soil that were collected in the early years of the Rothamsted field experiments were not taken in such a manner as to afford results applicable to our purpose. Commencing in 1856, however, the mode adopted has been, after carefully levelling the soil, to drive down a square frame, made of strong sheet-iron, open at top and bottom, and of an exact area, and of an exact depth, to the level of the surface. The inclosed soil is then carefully taken out, and its weight determined. The soil around the frame is then removed to the level of its lower edge, and it is again driven down, and the inclosed soil removed; and this process is repeated until the desired depth of sampling is reached.

Of surface soils, samples are taken from three, four, or as many as eight places on the same plot. A portion of each such sample is kept separate, as a means of testing the range of variation, and, if need be, of correction in case of any abnormal results due to accidental animal droppings, or other causes. Another portion of each separate sample of the surface soil is used to make a mixture of all. In the case of the subsoils, the separate samples of corresponding depth from the same plot are, as a rule, at once mixed. Surface soils are sometimes taken of an area of 12 by 12 inches, but frequently of only 6 by 6 inches, and subsoils almost invariably of the smaller area. The depth of each sample is generally 9 inches; but in some special cases it has been only 3 inches, and in some 6 inches. It is perhaps to be regretted that the depth originally fixed upon did not more nearly represent that to which the soil is more directly affected by the mechanical operations, and by the application of manure, say 6 inches. But having originally adopted 9 inches, it has been necessary to adhere to this depth subsequently, in order, as far as possible, to obtain comparable results at different dates.

The soils when brought to the laboratory are first broken up, and then partially dried in a stove-room at a temperature of about 130° F., to arrest nitrification, which would be liable to take place if the soils

amount of nitrogen per acre. It wil
withstanding the means adopted to se
dry mould per acre calculated for a
taken, vary considerably for the same
ing to the dryness or wetness of the s
as affected by the crop, the mechanic
stances. The amounts also vary ver
adjoining fields.

Nitrogen in the Soils of the Ex

The first series of determinations
will be called relates to those made in
Broadbalk field, which has now grow
succession, and the yield of nitrogen
no nitrogen in manure, has been given
bered that, under those conditions, th
in the annual yield of nitrogen in the
and with a mixed mineral manure use

The first wheat crop of the seri
although isolated samples of the soil
was not until 1856 that any were coll
At that date only four plots were sa
the first 9 inches. Eight samples w
plot, each 12 by 12 inches area, and

crop had been removed. It is obvious that, if the results at these two periods are to be compared, we must first determine whether the samples taken represent layers of equal depth and weight in the two cases. Confining attention on the present occasion to the results relating to the first 9 inches of depth, the following figures show the average weight of dry mould per acre; that is, of soil excluding stones and moisture, calculated from the weight of the samples taken, and from the results of the mechanical separation, and of the determination of moisture in the soils. For 1865, the calculations are based on the results afforded by 80 samples, eight from each of ten of the eleven plots, the eleventh being the one annually receiving farmyard manure; and for 1881 they are based on the results relating to 114 samples, that is, six samples each from 19 plots, again excluding the one with farmyard manure.

Number of Samples.	Calculated dry Mould per Acre.
	lbs.
1865, 10 plots, 8 samples from each	2,299,038
1881, 19 plots, 6 samples from each	2,552,202

The importance of taking samples of definite area and depth, and of determining the weights, is here strikingly illustrated. Thus, it is obvious that the samples analysed in 1881 represented, on the average, almost exactly one-ninth more soil per acre than those analysed in 1865. In other words, if the samples of 1865 fairly represented 9 inches of depth in the average condition of consolidation of the soil, those of 1881 represented 10 inches of soil in the same condition: that is, they included 1 inch more of subsoil, with its much lower percentage of nitrogen than the 9 inches above it. It may, of course, be a question whether the condition of consolidation of the soil was the more normal at the one period or at the other. It would, however, make scarcely any difference in the relation of the results to one another at the two periods, whether the actually determined percentages of nitrogen in the 1865 samples were lowered, on the assumption that they should have included 1 inch more of subsoil, or whether the determined percentages in the 1881 samples are raised, on the assumption that they contained 1 inch too much of subsoil. We have concluded, from a consideration of all the facts at command, that the latter alternative is upon the whole the best. We adopt,

deep), of the unmanured plot,
sampled in 1865, the actually
the dry mould; and for the 188
both the actually determined per
calculated as above described.
nitrogen per acre, reckoning 2,3
for 1865 according to the actu
1881 according to the corrected
more (+), or less (−), in 1881
for each period, there are given
the other plots than on plot 5a,
alone.

As already said, in 1865 the
wheat in succession, and in 1881
unmanured from the commence
manure in the first year, but th
since. The remaining plots were
the first eight of the thirty-eight
has been manured every year fo
years, as described in the table.

It will be observed that, for e
show a lower percentage of nitrog
rected percentages for 1881 are, c
actual determinations; and they.

Table IX.—Broadbalk Field Soils.

Nitrogen, per cent. in the dry Mould, and per Acre.

[Wheat thirty-nine years in succession, 1843–1844 to 1881–1882, inclusive.]

Plots.	Manures, per acre, per annum (as in 1851–52 and since).	Nitrogen. Per cent. in dry Mould. 1865. Actual.	1881. Actual.	1881. Corrected.	Per Acre, 2,300,000 pounds dry Mould. 1865.	1881.	1881 + or – 1865.	+ or – plot 5a. 1865.	1881.	1881 + or – 1865.
		Per cent.	Per cent.	Per cent.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3	Unmanured (1843–44 and since)	0·1090	0·1009	0·1045	2507	2404	–103	—	—	—
5a	Mixed mineral manure	0·1119	0·0981	0·1012	2574	2328	–246	—	—	—
7a	Mixed mineral manure, and ammonia salts = 86 lbs. nitrogen	0·1230	0·1207	0·1264	2829	2908	+ 79	+255	+580	+325
9a	Mixed mineral manure, and nitrate of soda = 86 lbs. nitrogen	0·1232	0·1200	0·1253	2834	2883	+ 49	+260	+555	+295
10a	Ammonia salts = 86 lbs. nitrogen (1845 & since)	0·1108	0·1034	0·1074	2548	2471	– 77	– 26	+143	+169
11a	Ammonia salts = 86 lbs. nitrogen, and superphosphate	0·1171	0·1121	0·1164	2693	2676	– 17	+119	+348	+229
12a	Ammonia salts = 86 lbs. nitrogen, superphosphate, and sodium sulphate	0·1208	0·1155	0·1202	2778	2765	– 13	+204	+437	+233
13a	Ammonia salts = 86 lbs. nitrogen, superphosphate, and potassium sulphate	0·1206	0·1191	0·1245	2774	2863	+ 89	+200	+535	+335
14a	Ammonia salts = 86 lbs. nitrogen, superphosphate, and magnesium sulphate	0·1197	0·1163	0·1215	2753	2794	+ 41	+179	+466	+287
16a	Ammonia salts = 172 lbs. nitrogen, and mixed mineral manure*	0·1264	0·1066	0·1112	2907	2557	–350	+333	+229	–104

exhaustion. Taking the resu
third 9 inches, the calculated lo
mately the same for the two plo
9 inches only are, however, suffi
yield of nitrogen in the crop, wh
is accompanied by a decline in t

A further illustration on thi
plot 16a. For the thirteen y
besides the mixed mineral manu
any of the other plots, the resu
and it gave on the average of t
acre per annum. Since 1864, h
manured, and during the seventee
average of only 14¾ bushels of gr
has been very little more than
mineral manure. The table sho
crop had been removed since the
nium salts, the surface soil still c
than any other plot in the serie
years more of cropping without m
plot was reduced by a greater am
a lower point than on any other
plot 10 with the ammonium salts

Let us now refer to the last

ences. The plots under consideration, all of which received the same amount of nitrogen in manure, are there given in the order of their average annual increased yield of nitrogen in the crops over plot 5. The first column shows the estimated average annual increased yield of nitrogen per acre in the crops; the second, the estimated annual loss of nitrogen as nitric acid by drainage; the third, the estimated annual excess of nitrogen in the surface soil over that on plot 5 with the mineral manure alone; and the last column shows the relation which that excess in the soil bears to 100 increased yield of nitrogen in the crops.

TABLE X.

Estimated Nitrogen per Acre per Annum.

Plots.		In Crops over Plot 5.	Loss by Drainage over Plot 5.	In Surface Soil 9 inches deep, over Plot 5.	Excess in Surface Soil to 100 increase in Crop.
		lbs.	lbs.	lbs.	lbs.
10	Ammonia salts = 86 lbs. nitrogen (1845 and since)	12·4	31·2	4·8	38·7
11	Ammonia salts = 86 lbs. nitrogen and superphosphate............	17·7	28·5	11·6	65·5
12	Ammonia salts = 86 lbs. nitrogen superphosphate and soda	22·2	24·5	14·6	65·8
13	Ammonia salts = 86 lbs. nitrogen superphosphate and potash	23·4	25·6	17·8	76·1
14	Ammonia salts = 86 lbs. nitrogen superphosphate and magnesia ..	24·1	27·5	15·5	64·3
7	Ammonia salts = 86 lbs. nitrogen and mixed mineral manure	25·9	19·0	19·3	74·5
9	Nitrate soda = 86 lbs. nitrogen and mixed mineral manure	26·5	23·7	18·5	71·2

It is seen that the increased yield of nitrogen in the crops also varied exceedingly with the same amount supplied in manure, according to the condition as to supply of mineral constituents. Plot 10, with the ammonium salts alone, gives the smallest increased yield of nitrogen in the crop; and plots 7 and 9, with the most complete mineral manure, each more than twice as much; the other plots giving intermediate amounts.

The order of the estimated loss of nitrogen by drainage is almost the converse of that of the increased yield in the crops. Plot 10, which gives the least increased yield in the crop, shows the greatest

loss by drainage; and plots 7 and 9, which yield the greatest increase in the crop, show the least loss by drainage.

The excess in the soils (over plot 5) is obviously much more in the order of the increased yield in the crops. Plot 10, with the least in the increase of crop and the most in the drainage, shows the least excess in the soil; whilst plots 7 and 9, with the greatest increased yield in the crop, and the least loss by drainage, show the greatest excess in the soil.

It is clear, therefore, that whilst the excess in the soil has no direct relation to the amount supplied in the manure, it has a very obvious relation to the increased yield in the crop; in other words, to the amount of growth. The last column of the table brings this out more clearly. Excepting in the case of plot 10, with the ammonium salts alone, there is a general uniformity in the proportion of the excess in the soil over plot 5 to the increased yield in the crop over plot 5; and the variations, such as they are, have an obvious connection with the conditions of growth. Thus, plots 11, 12, and 14, all with a deficient supply of potash, show approximately equal proportions retained in the soil for 100 of increase in the crop. Plots 13, 7, and 9, again, all with liberal supplies of potash, show higher, but approximately equal, proportions retained in the surface soil for 100 of increased yield in the crop.

Upon the whole, it is obvious that the relative excess of nitrogen in the soils of the different plots is little, if at all, due to the direct retention by the soil of the nitrogen of the manure, but is almost exclusively dependent on the difference in amount of the residue of the crops—of the stubble and roots, and perhaps of weeds.

Recurring to the main point which it is our object to elucidate, there can be no doubt that the determinations of nitrogen in the surface soils of the plots of the experimental wheat field, at different dates, establish the fact that the decline in the yield of nitrogen in the crops, when none is supplied in manure, is accompanied by a decline in the stock of nitrogen in the soil.

It will be well to consider, as far as the data at command will allow, what relation the yield of the nitrogen in the crops bears to the loss of nitrogen by the soil?

On this point it may be stated that, taking the average of thirty years, 1852—1881, it is estimated that the unmanured plot yielded 18·6 pounds of nitrogen in the crops, and lost 10·3 pounds in the drainage, or in all 28·9 pounds per acre per annum over that period. In like manner, it is estimated that plot 5, which received nitrogenous as well as mineral manure during the preceding eight years,

but mineral manure alone during the thirty years, yielded an average of 20·3 pounds of nitrogen in the crops, and 12 pounds in the drainage, or in all 32·3 pounds per acre per annum. It would thus appear that, without nitrogenous manure, about 30 pounds of nitrogen has been contributed per acre per annum, from some source, to crop and drainage together. The determinations of nitrogen in the soils of the two plots indicate that they have lost an average of about two-thirds of this amount annually to the depth of 27 inches. There would, therefore, according to this reckoning, remain about one-third —say 10 pounds more or less—to be contributed by seed, by rain and condensation from the atmosphere, and by all the other supplies of combined nitrogen which have been supposed to be available, whether by the combination of free nitrogen within the soil, or its assimilation by the plant. Of this amount about 2 pounds will be due to seed, and if we suppose, say, only 5 pounds to be annually supplied by rain and the minor aqueous deposits from the atmosphere, there is but little left to be provided by all the other sources assumed.

Nitrogen in the Soils of the Experimental Barley Plots.

Unfortunately we have not so complete a series of determinations of nitrogen in the soils of the experimental barley plots as of those in the experimental wheat field. In 1868 four of the barley plots were sampled. Four samples, each 6 by 6 inches area, by 9 inches deep, were taken from each plot, and the four mixed together. In March, 1882, 26 plots were sampled, four samples being taken from each plot, each 6 by 6 inches area, and to the depth of three times 9, or 27 inches. Of the plots sampled in 1868 only one had received no nitrogenous manure, but we are able to give the percentage of nitrogen in the surface soil of this plot at the two dates.

TABLE XI.—HOOSFIELD BARLEY LAND.

Nitrogen, per cent. in the dry Mould, first 9 inches.

[Barley, 31 years in succession, 1852–1882 inclusive.]

Description of Manure.	1868.	1882.
	Per cent.	Per cent.
Mixed mineral manure alone	0·1202	0·1124

The calculated average weights of dry mould per acre, to the depth of 9 inches, were not very different at the two dates. The 1882 samples

were, however, slightly the heavier, which would indicate that, for comparison, the percentage of nitrogen given for the latter date is perhaps somewhat too low. Still, it is obvious that, as in the case of the wheat land, so also in that of the barley land, there is, with the decline in the yield of nitrogen in the crop at the same time a decline in the stock of the nitrogen in the soil.

Nitrogen in the Soils of the Experimental Root-crop Plots.

The next results relate to the land upon which root-crops—common turnips, swedes, sugar-beet, and mangel-wurzel (with the exception of the interpolation of three years of barley without manure) have been grown for forty years in succession, 1843–1882 inclusive. Samples of the soil have only been taken once, namely, in April, 1870; that is, after the experiment had been continued twenty-seven years. At that time 35 plots were sampled, and four samples were taken from each plot, each 6 by 6 inches area, and to a depth of 3 times 9, or 27 inches.

The following table shows the percentage of nitrogen in the surface soil of the continuously unmanured plot, and of three plots with mineral manure alone:—

TABLE XII.—BARNFIELD ROOT-CROP LAND.

Nitrogen, per cent. in dry Mould, first 9 inches.

[Root-crops (except barley three years) 40 years in succession, 1843–1882 inclusive.]

Description of Manure.	1870.
	Per cent.
Plot 3.—Unmanured	0·0852
Plot 4.—Mixed mineral manure....................................	0·0934
Plot 5.—Superphosphate alone	0·0888
Plot 6.—Superphosphate and potash................................	0·0867
Mean of plots 4, 5, 6................................	0·0896

Having only taken samples once, we have, of course, no means of comparing the condition of the land as to its percentage of nitrogen at different periods. The point to be observed in the results given in the table is, that each of these four plots, which have received no nitrogenous manure, shows, after twenty-seven years of experiment (twenty-four years roots and three years barley), a lower percentage of nitrogen

in the surface soil than has been found in any of the other experimental fields; though determinations made in samples from other parts of the same field, and also in an adjoining field, show considerably higher results. The nearest approach to so low an amount in any other field is where the land had been under alternate wheat and fallow, without manure, for more than thirty years.

It will be remembered that the root-crops gave, with mineral manure alone, a very much higher yield of nitrogen than the cereals in the earlier years, and as low a yield in the later years. That they did not give less still is probably owing to the fact that their growth extends later in the season than that of the cereals, by virtue of which they are probably enabled to arrest the nitric acid formed within the soil during the early autumn months, which in the case of the cereals would be more subject to loss by drainage.

Both the mechanical conditions of surface soil known to be favourable for the growth of the root-crops, and the large amount of fibrous root they throw out near the surface, are indications of an active demand on the resources of the upper layers of the soil, and are perfectly consistent with the supposition that their growth has led to a greater reduction in the stores of nitrogen of the superficial layers than in the case of any of the other crops.

The evidence afforded, both by the facts of production, and by the determinations of nitrogen in the soil, is indeed strongly in favour of the view that the source of the nitrogen of the root-crops, as of the cereals, is, when grown without nitrogenous manure, the soil itself, and the small quantity of combined nitrogen annually contributed by rain, and the minor aqueous deposits from the atmosphere. It is said, however, that these crops require a certain amount of nitrogen to be supplied by manure, and that they are able to take up the remainder from atmospheric sources. The facts of production recorded at page 11 afford no countenance to such a view. We conclude, indeed, that the dependence of these crops for their nitrogen, on the stores of the soil itself, or on supplies by manure, is as clearly established as in the case of the cereals.

Is the Soil a Source of the Nitrogen of the Leguminosæ?

We have now to consider the bearing of the evidence on the question of the sources of the nitrogen of the Leguminosæ; and here we approach not only the most important but the most difficult part of our subject.

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Nitrogen in the Soils of the

The most important of the leg
has been made is red clover. In
nitrogen over twenty-two years, 18
ever, was any crop obtained. The
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in nine of the last ten trials the pla
and spring succeeding the sowing
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taken from five places where no nit
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each. Exactly corresponding sampl
diately adjoining plot, which had b
wheat and fallow, without manure
determined in each of the five separ
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TABLE XIII.—HOOSFIELD CLOVER, AND WHEAT AND FALLOW, LAND.

Nitrogen per cent. in dry Mould, first 9 inches.

[Experiments more than 30 years.]

Mean.	1881.	
	Clover Land.	Fallow Land.
	Per cent.	Per cent.
Mean of determinations on five separate samples......	0·1067	0 0925
Mean on the mixture of the five samples............	0·1055	0·0984
Mean	0·1061	0·0955

It is true that the tendency of the evidence on the point is to show that red clover derives, at any rate much of its nitrogen, from the lower layers of the soil; but it is surely significant that, after the growth of heavy crops in 1849, when the land was in ordinary condition as to manuring and cropping, and the constant failure since, there is, coincidently with this, nearly as low a percentage of nitrogen in the surface soil as with alternate wheat and fallow without manure. It is obvious that any accumulation near the surface, due to residue from the small crops, has been more than compensated by exhaustion. The evidence afforded by the figures may be said to be of a somewhat negative character; but it is at any rate clear that failure of growth of the clover has been associated with a declining, and a very low, percentage of nitrogen in the surface soil.

The next results are of a very much more definite character. They relate to the two portions of the field which had grown six corn crops in succession by artificial manures alone, was then divided (in 1873), and on one half clover (sown in the previous year), and on the other half barley, was grown. Table I shows that in the clover crops 151·3 pounds, and in the barley only 37·3 pounds of nitrogen were removed. Yet, in the next year (1874), barley being grown over both portions, the one which had yielded 151·3 pounds in clover now yielded 69·4 pounds in barley; and the other, which had yielded only 37·3 in barley, now yielded only 39·1 pounds in barley.

In October, 1873, after the clover and barley had been removed, and before the land was ploughed up, samples of the soil were taken as follows: From each portion four separate samples, each 12 by 12 inches area and 9 inches deep, and the nitrogen was determined in

each separate sample, and also in an equal mixture of the four. Six other samples, each 6 by 6 by 9 inches, were also taken from each of the two portions, and the six samples representing each portion were mixed, and the nitrogen determined in the mixture. At each place corresponding separate samples were taken, and mixtures made, representing respectively the second and the third 9 inches of depth. In all cases three and in many four determinations of nitrogen were made on each sample. The following table gives the mean results on each of the four separate samples, the mean of these, the mean on the mixture of the four, the mean on the mixture of the six, and the mean of all:—

TABLE XIV.

Experimental Clover and Barley Land.

[Nitrogen per cent. in dry Mould, first 9 inches.]

Description of Samples.	1873.	
	Clover Land.	Barley Land.
	Per cent.	Per cent.
Sample No. 1 (12 × 12 × 9 inches)	0·1574	0·1408
Sample No. 2 (12 × 12 × 9 inches)	0·1529	0·1341
Sample No. 3 (12 × 12 × 9 inches)	0·1484	0·1431
Sample No. 4 (12 × 12 × 9 inches)	0·1631	0·1465
Mean on the four separate samples (12 × 12 × 9 inches)	0·1554	0·1411
Mean on a mixture of the four samples (12 × 12 × 9 ins.)	0·1566	0·1387
Mean on a mixture of six samples (6 × 6 × 9 inches)	0·1578	0·1450
General means	0·1566	0·1416

The determinations on the individual samples given in the upper portion of the table (XIV), forcibly illustrate the inapplicability of results obtained on single samples of soil. But the accordance of the mean results of the three sets of determinations for the clover land, and again of the three for the barley land, can leave no doubt whatever that there was a considerably higher percentage of nitrogen in the first 9 inches of the clover ground than to the same depth of the barley ground.

The results must, indeed, be accepted as indicating a marked distinction, which, in direction, is entirely consistent with what is known of the influence of a clover crop as a preparation for a succeeding cereal one, and entirely consistent with the results actually obtained with the barley succeeding the clover

that the figures correctly represent, in degree, the average difference in the composition of the first 9 inches of the two plots; for, calculated per acre, the excess of nitrogen in the surface soil of the clover plot would represent an accumulation equal to about twice as much as was removed in the three cuttings of the clover, notwithstanding all visible vegetable *débris* was removed before the soils were submitted to analysis;* nor have the subsequent crops benefited as much as might have been expected from such an amount of accumulation. On the other hand, samples taken in 1877 still show a higher percentage of nitrogen in the surface soil of the clover than of the barley land.

It is, at any rate, obvious that the surface soil of the clover ground has gained nitrogen, either from above or from below—from the atmosphere or from the subsoil. And, so far as the determinations of nitrogen in the subsoils go, the indication is that, if from below, it is at least mainly from a lower depth than 27 inches.

It is freely admitted that, in the facts of this experiment as they stand, there is no evidence as to the source of the large amount of nitrogen of the clover crop, and of the increased amount of it in the surface soil. In the absence of such evidence, it is natural enough to assume that the atmosphere has been the source. But whilst there is absolutely nothing in favour of this view excepting the fact that an explanation is needed, and that if that source were established the difficulty would be solved, there is, to say the least, much more evidence in favour of the supposition that the subsoil has been the source of at any rate much of the nitrogen.

The Soils of the Melilotus leucantha and White Clover Plots.

Reference has already been made to the enormous growth of *Melilotus leucantha*, and the enormous amount of nitrogen it yielded, for several years in succession, on the land where no nitrogen had been applied for more than thirty years, and where red clover had so frequently failed (p. 12). The crop of 1882, the fifth in succession, was the highest, and the yield of nitrogen in it was not far short of 150 pounds per acre; whilst, under exactly similar conditions, ordinary red and white clover gave very small produce. Accordingly, as soon as the crops were removed, samples of soil were taken from one of the *melilotus* plots, and from the corresponding white clover plot. Samples were taken from two places on each plot, and in each case to

* This was more completely done in the case of the four 12 × 12 × 9 inch samples, than in that of the six 6 × 6 × 9 inch ones, and the latter are seen to give slightly higher percentages of nitrogen.

the depth of six times 9 inches, or in all 54 inches. The examination of these samples of soil is as yet very incomplete, but the following interesting facts have been ascertained :—

Whilst the strong roots of the *melilotus* were found to penetrate to the lowest depths of the sampling, there was very little development of white clover roots beyond the surface soil. Whilst to the eye, and to the hand, the subsoil where the *melilotus* had grown was obviously pumped dry, and was somewhat disintegrated, to the full depth sampled, that of the clover plot had no such characters. Determinations of moisture in the soils and subsoils show, at each of the six depths, much less water in the *melilotus* than in the white clover soils; and the difference is by far the greater in the lower depths. Calculated per acre, it would appear that, to the depth of 54 inches, the *melilotus* soil had lost approximately 540 tons more water per acre than the white clover soil; and there can be no doubt that the pumping action had extended deeper still.

There is here, then, clear evidence that the plant, whose habit of growth, and especially whose range, and feeding capacity, of root, suited it to the conditions, was enabled to take up much more water, and doubtless with it much more food, than, under exactly similar conditions of soil, were at the command of the plant of the much weaker and more restricted development.

Nitrogen as Nitric Acid in the Melilotus and White Clover Soils.

That the deep-rooting *melilotus* did derive more nitrogen from the subsoil than the shallow-rooting white clover is obvious from the following facts:—Watery exhausts were made of each soil, at each depth, and the nitrogen as nitric acid determined in them, by Schlösing's method, as nitric oxide, by its reaction with ferrous salts.

The following table summarises the results :—

TABLE XV.

Nitrogen as Nitric Acid.

	Per million, dry Soil.		Per Acre.		
	Melilotus Soil.	White Clover Soil.	Melilotus Soil.	White Clover Soil.	Difference.
			lbs.	lbs.	lbs.
'irst 9 inches........	1·28	3·24	3·39	8·59	5·20
econd 9 inches......	0·36	1·10	0·97	2·97	2·00
hird 9 inches.......	0·21	0·66	0·61	1·91	1·30
ourth 9 inches......	0·33	1·03	0·99	3·09	2·10
ifth 9 inches.......	0·28	1·46	0·84	4·38	3·54
ixth 9 inches.......	0·55	1·77	1·65	5·31	3·66
Total...........	..	..	8·45	26·25	17·80

Thus the *melilotus* had not only exhausted the water, but the nitric cid of the soil, at each depth very much more than the white clover ad done; and the difference is very marked, and increases, at the ›wer depths. It is seen that in the case of the white clover soil there a diminishing amount of nitric acid from the first to the third depth, nd then an increasing quantity to the sixth depth. There was, in act, about the same total amount found in the three lower as in the hree upper layers. It may fairly be supposed that there is greater oncentration lower still, and that the exhausting action of the *melilotus* xtended beyond the depth examined.

There is here direct evidence that the soil is the source of at ny rate some of the excess of nitrogen of the *melilotus* over that in he white clover. The quantity, and the distribution, of nitric acid n the soil at any one time are so dependent on temporary conditions, hat it would be fallacious to attempt to estimate from the figures as hey stand the exact amount which the *melilotus* has taken up more han the white clover. Then it is obvious that the action extended elow the depth examined; and it is a question whether, with the reater disintegration, and greater aëration, nitrification would not be avoured in the lower depths, and if so the supply would be in a sense umulative. Lastly, it may be that the deeply and widely distributed *nelilotus* roots have the capacity of taking up nitrogen from the soil n other forms than as nitric acid.

Nitrogen as Nitric Acid in other Soils and Subsoils.

It will be some further aid in judging of the possibility or probability that the nitric acid in the soil and subsoil may be an adequate source of the nitrogen of the Leguminosæ, if we quote a few results indicating the amount of nitric acid found in some other soils under known conditions.

In the first place, three soil drain-gauges, one with 20, one with 40, and one with 60 inches depth of soil, in its natural state of consolidation, and each of one-thousandth of an acre area, have been under experiment for between eleven and twelve years. No manure has been applied to these soils, nor have they grown any crop, from the commencement. The drainage has been regularly collected and measured; and for nearly the whole of the last five years the nitric acid has been determined in monthly average samples of the drainage waters. Taking the result of the three gauges, for four harvest-years (September 1, 1877, to August 31, 1881), these soils, which had been about six years without any manure at the commencement of the period under consideration, have lost by drainage an average of nearly 43 pounds of nitrogen as nitric acid per acre per annum, of which perhaps not much more than 5 pounds would be due to rain and condensation of combined nitrogen from the atmosphere. In fact, about 35 pounds, or perhaps more, would appear to have been annually due to the nitrification of the nitrogenous matter of these unmanured soils. It has to be borne in mind, however, that the blocks of soil having access of air from below as well as from above, the nitrification may have been freer than it would be in soil in its ordinary condition.

Again, in some of the samples of soil taken from the plots in the experimental wheat field, in October 1865, and in many of those taken in October 1881, that is in each case about two months after the removal of the crop, the nitric acid has been determined.

In the case of one plot sampled in 1865, which had received annually mixed mineral manure and ammonium salts, determinations made in 1866 (by Dr. Pugh's method), showed nearly 76 pounds of nitrogen as nitric acid per acre to the depth of 27 inches. As, however, these soils had been stored in a rather moist condition, it is possible that nitrification may have taken place after the collection, and that the results are so far somewhat too high.

The following table (XVI) gives an abstract of the results of the determinations of nitrogen as nitric acid in the 1881 samples of the experimental wheat field soils:—

TABLE XVI.

Nitrogen as Nitric Acid.

	Complex Mineral Manure		Sodium Nitrate alone.	Unmanured continuously.
	and Ammonium Salts.	and Sodium Nitrate.		
Per Million Dry Soil.				
nches	8·95	7·73	6·38	3·80
) inches	4·17	3·69	7·43	1·94
inches	2·07	2·98	6·44	1·00
Per Acre.				
	lbs.	lbs.	lbs.	lbs.
nches	22·8	19·7	16·3	9·7
) inches	11·3	10·0	20·1	5·2
inches	5·8	8·3	18·0	2·8
Total	39·9	38·0	54·4	17·7

ns, in these 1881 samples, collected, like those in 1865, about nths after the removal of the crops, the amounts of nitric acid to the depth of 27 inches only, represented—in the soil of the eceiving mixed mineral manure and ammonium salts, 39·9 s of nitrogen per acre to that depth; in that of the plot receiving me mineral manure and sodium nitrate, 38 pounds; in that of t to which nitrate of soda alone is annually applied, 54·4 pounds; the soil of the continuously unmanured plot, 17·7 pounds.

in the case of the white clover land, in all cases (except with the alone), the amount decreased from the first to the third 9 inches th from the surface; and if, as in that case, it increased in the lepths, and in anything like the same degree, we have evidence nsiderable store of nitric acid available for such plants as, by of their habit of growth, are able to gather up the residue ulated within the subsoil.

terminations made in samples collected in the experimental rotaeld, in September 1878, showed the following amounts of n as nitric acid per acre to the depth of 18 inches :—

Samples collected at the same
wheat and fallow plots showed to t

After fallow...........	
After wheat...........	
Difference	

Lastly, two fields which had b
ordinary course of the farm, and h
autumn, showed, according to dete
October 1881, the following amou
acre to the depth of 27 inches:—

Claycroft field..........	
Foster's field	

Thus there was very much less r
soils to the depths examined, after t
beans, as well as after that of the g
corresponding fallow soils; indica
some, at any rate, of the nitrogen o

It will be seen, however, that
receiving nitrogenous manure, the s
depths examined is very far from

iot to be expected that the amount found within such limits at any ;iven time would represent more than a fraction of that which would e available, even within that range, during the long period of growth f the clover crop. Then, the indications are that there is considerable ccumulation beyond the depth to which most of our examinations pply. Still, it is difficult to suppose, with the evidence at command, hat the whole of the nitrogen which has to be accounted for, either n the *Melilotus*, or in the clover and barley experiment, can be ttributed to that source. There remains the question whether the oots of the plant do not take up nitrogen from the soil in other tates than as nitric acid.

Finally in regard to the experiments with clover and barley, it is dmitted that the various results of soil examinations which have een adduced do not conclusively show the source of the whole of he nitrogen to have been the soil. It will, we think, nevertheless e granted, that they do clearly point to the fact that at any rate nuch of it is derived from that source; whilst there is no evidence vhatever of an atmospheric source of more than the small amount of ombined nitrogen coming down in rain, and the minor aqueous leposits, and the probably still smaller amount absorbed from the tmosphere by the porous soil.

Vitrogen in some of the Soils of the Experimental Mixed Herbage Plots.

The results next to be referred to will afford additional evidence of he soil-source of the nitrogen of the Leguminosæ.

In Table III it was shown that in the mixed herbage of permanent rass land, without manure 33·0 pounds, and with a purely mineral nanure (including potash) 55·6 pounds of nitrogen were yielded per cre per annum in the crop over a period of twenty years. Whence omes the 22·6 pounds more nitrogen per acre per annum taken up when the mineral manure was applied than without manure?

After twenty years of continuous experiment, samples of soil were taken from three places on each plot, and in each case to the epth of six times 9 inches, or 54 inches. The mean results of the eterminations of nitrogen in the surface soils of the unmanured lot, and of the plot receiving a complex mineral manure (including otash), are given in Table XVII which follows:—

TABLE XVII.—EXPERIMENTS ON PERMANENT MEADOW LAND.

Nitrogen, per cent. in dry Mould, and per Acre.

	1870.	1876.	1878.
	Per cent.	Per cent.	
Plot 3.—Unmanured	0·2517	0·2466	..
Plot 7.—Mixed mineral manure, including potash	..	0·2236	0·2246
Difference	..	0·0230	..
		lbs.	
Difference per acre .. { Total 20 years	..	506·0	..
Difference per acre .. { Average per annum	..	25·3	..

Although we have not previously quoted the figures, we have on several occasions stated in general terms that determinations of nitrogen show a lower amount in the mineral-manured soil, approximately corresponding to the increased yield in the crop.

It is in reference to our statements on this point that M. Joulie has called in question the possibility of obtaining results of the kind applicable to our argument. He takes the fact of the increased yield of nitrogen under the influence of purely mineral manure as conclusive proof of the atmospheric source of the increased amount of nitrogen assimilated. He assumes that our calculations are based on determinations of nitrogen in a sample of the mixed soil to the total depth of 54 inches. He calculates that in the mass of soil to that depth the difference in the amount in the two cases would be far too small to furnish a justification for the important conclusion that the soil was the source of the nitrogen. He objects that the roots of such herbage would derive their nutriment chiefly in the superficial layers. He further objects that if the difference we assume were a fact, it is probably due to an accidental difference in the soil of the two plots, such a difference having been admitted by us in the case of another plot. Lastly, he suggests that if there really were the reduction we suppose, it might be due to other causes—such as increased activity of nitrification under the influence of the mineral manure and passage of the nitrates downwards.

In the first place, in the case of the irregularity in the condition of one of the plots referred to, the difference was readily seen in the section of the soil, and there was no such difference in the instance now under consideration.

Then it is the determination of nitrogen in the first 9 inches of soil

lone, to which we have hitherto referred, and to which we confine ttention on the present occasion.

In the next place, that the difference in the condition of the two lots is not merely local is shown by the fact that the determinations n a sample from the unmanured plot taken in 1870 entirely confirm he relative composition shown by the samples of 1876. Again, the ower percentage of nitrogen in the 1876 samples of the mineral nanured plot is entirely confirmed by the results obtained on samples aken in 1878. Further, of the twenty experimental plots, there is nly one other showing so low a percentage as the mineral-manured lot, and that is the one which had received the same mineral manure, ut for a shorter series of years.

We have in fact no doubt whatever that the differences indicated by he figures are real, and dependent on the conditions of manuring and f growth. The reduction is, moreover, very great, amounting to early one-tenth of the total quantity of nitrogen, and far beyond he limits of accidental difference in the sampling or the analysis.

Calculated per acre, the surface soil of the mineral-manured plot ontained, at the end of the twenty years, 506 pounds less nitrogen than he soil of the unmanured plot to the same depth, corresponding to an nnual reduction of 25·3 pounds of nitrogen per acre per annum. It s, to say the least, a very remarkable coincidence that the increased ield of nitrogen in the crop on the mineral-manured plot which has o be accounted for is 22·6 pounds per acre per annum.

We do not pretend to claim absolute accuracy for such results, but re ourselves entertain no doubt whatever of their significance and heir importance.

It will be asked—How is it that in the case of the red clover, and he *melilotus*, it was concluded that, so far as the plants had derived heir nitrogen from the soil, it was at any rate mainly from the lower epths, and that here, in the case of the permanent mixed herbage lots, we assume the increased yield of nitrogen to be derived from he surface soil?

Under the influence of the mineral manure, a larger proportion nd amount of leguminous herbage was developed than on any other lot; but the leguminous plant the most, indeed very prominently, avoured was the *Lathyrus pratensis*, which throws out an enormous uantity of root near the surface; and it is sufficiently established hat the potash of artificial manures remains almost exclusively in the uperficial layers. On the other hand, the perennial red clover, and he *Lotus corniculatus*, which have a much more deeply-rooting tenency, are comparatively little encouraged.

The actual amount of leguminous herbage produced, however, is not sufficient to account for nearly the whole of the increased yield of nitrogen in the produce of the plot. The fact is that, besides a porportionally very large increase in the growth of leguminous herbage, there has been a gradually increasing amount of gramineous produce developed; far beyond what would be anticipated from the extremely limited effect of such manures on gramineous crops grown separately on arable land. How far this result may be due to an increased tendency of the grasses to form stem, and to ripen, under such conditions;—how far to more active nitrification induced under the influence of the mineral manure in the much more highly nitrogenous grass-land than in the poorer arable soil, and so yielding a direct supply to the Gramineæ of the mixed herbage;—or how far to an increased supply in a condition available for the grasses as the result of a previously increased growth of the Leguminosæ, may be a question. But it is of interest to note that the gramineous species that are developed are among the most superficially rooting of the grasses found on the experimental plots.

Before leaving the subject of these experiments on the mixed herbage of grass land, it may be well to call attention to the fact that, on the assumption that the whole of the nitrogen of the herbage, beyond the small amount of already combined nitrogen contributed by rain and condensation from the atmosphere, is derived from the soil, we have to conclude that about 25 pounds per acre per annum have been yielded by the soil of the unmanured plot, and nearly an additional 25 pounds, or in all about 50 pounds, from the mineral-manured plot. It was estimated that, in the case of the continuous wheat experiments, about 20 pounds of nitrogen had been annually obtained in the crop, and a minimum of 12 pounds lost by drainage; in all 32 pounds. It cannot fail to be observed how closely this amount corresponds with the annual yield of nitrogen (33 pounds) in the unmanured mixed herbage. With the richer grass-land, though less aërated than arable land, it might be expected there would be some increased activity of nitrification, even in the unmanured soil; and there may be some loss by drainage. But, with a mixed herbage of some 50 species, of very varying habit of growth, and with the possession of the soil all the year round, it is only what would be expected that there would be more of the available nitrogen taken up by the crop, and less lost by drainage, than with the cereal grown separately on arable land, and occupying the soil for only a very limited period of the year.

We conclude, then, that the results [illegible]

herbage plots can leave little doubt that the increased yield of nitrogen in the more highly leguminous produce of the mineral-manured plot had its source in the stores of the soil itself.

Source of the Nitrogen of Clover Grown on Rich Garden Soil.

We have one more illustration to bring forward having an important bearing on the question of the sources of the nitrogen of the Leguminosæ.

In view of the signal failure in the attempts to grow red clover on a nitrogen exhausted arable soil, it is of much interest that large, though declining, crops have been grown for twenty-nine years in succession on a small plot of rich kitchen-garden soil.

The experiment was commenced in 1854, and the following table shows the percentage of nitrogen in samples of the first 9 inches of soil, taken in October 1857, and in May 1879; that is, with an interval of twenty-one seasons of growth. In 1857 only one sample was taken, and only to the depth of 9 inches; but in 1879 three samples were taken, in each case to the depth of twice 9, or 18 inches. The results given in the table relate to the first 9 inches of depth only:—

TABLE XVIII.—CLOVER GROWN ON KITCHEN GARDEN SOIL.

Nitrogen, per cent. in dry Mould, and per Acre.

	1857.	1879.	Difference.
	Per cent.	Per cent. 0·3635 0·3640 0·3626	Per cent.
	0·5095	0·3634	0·1461
	lbs.	lbs.	lbs.
Per acre, total*	9,528	6,796	2,732
Difference per acre per annum	..	..	130

The percentage of nitrogen given for the single sample collected in October 1857, is the mean of determinations made in 1857, 1866, and

* In the original paper, too high an average weight of soil per acre was adopted, and hence the amounts of nitrogen per acre were estimated to be higher than now given; but the *difference* was only 9 pounds more (139) than according to the new calculation.

1880, and is almost identical with the mean of those made at the latest date.

The first point to observe is that the first 9 inches of the garden ground contained more than half a per cent. of nitrogen, nearly four times as much as the average of the arable soils, and nearly five times as much as the exhausted clover land soil. It is of course true that the soil would be correspondingly rich in all other constituents; but some portions of the arable soil where clover failed, had received much more of mineral constituents by manure than had been removed in the crops.

The means of the determinations made on the three separate samples taken in 1879 are seen to agree very well, and the results can leave no doubt that there has been a great reduction in the stock of nitrogen in the surface soil. The reduction amounts to nearly 29 per cent. of the total. Reckoned per acre, as shown at the foot of the table, it corresponds to a loss of 2,732 pounds during the twenty-one seasons of growth; and although really good crops are still grown in most years, there has been, with this great reduction of the stock of nitrogen in the soil, a very marked reduction in the clover-growing capability of the soil. Thus, during the first fourteen of the twenty-nine years of the experiment, seed was sown only three times; whilst during the last fifteen years it has been necessary to sow ten times. It is obvious, therefore, that the plant stood very much longer during the earlier than the later years. Then, again, the produce from the three sowings during the first fourteen years was nearly twice as much as has been obtained since.

The question obviously arises—what relation does the amount of nitrogen lost by the soil bear to the amount taken off in the crops? We quite admit the uncertainty of calculations of produce per acre from the results obtained on a few square yards. We are, however, disposed to estimate the average yield of nitrogen over the twenty-one years between the two periods of soil sampling at about 200 pounds per acre per annum. The table shows that against this we have an estimated loss of nitrogen by the first 9 inches of soil of 130 pounds per acre per annum, corresponding approximately to two-thirds of the amount estimated in the crop.

There is, however, evidence leading to the conclusion that, in the case of arable soils to which excessive amounts of farm-yard manure are applied, there may be a loss by evolution as free nitrogen; and, obviously, so far as this may have occurred in the garden soil, there will be the less of the loss determined in the surface soil to be credited to assimilation by the growing clover.

On the other hand, it is known that when growing on ordinary arable soil, the clover plant throws out a large amount of roots in the lower layers, and although in the case of so rich a surface soil, the plant may derive a larger proportion of its nutriment from that source, we must at the same time suppose that it has also availed itself of the resources of the subsoil. Unfortunately, we did not sample deeper than 9 inches in 1857, so that we can make no comparison of the condition of the subsoil at the two periods. It may, however, be observed that, in 1879, the second 9 inches showed about three times as high a percentage as the subsoils of the arable fields at the same depth; indeed, not far from twice as high a percentage as several of the exhausted arable surface soils. It cannot be doubted, therefore, that the subsoil of the garden plot has contributed to the yield of nitrogen in the crop.

If, then, we have not here absolute proof that the source of the whole of the nitrogen of the clover growing on the garden soil was the soil itself, we have surely very strong grounds for concluding that much, and perhaps the whole of it, has been so derived.

General Conclusions.

After this review of the evidence which the determinations of nitrogen in the soils of our experimental plots afford, we end, as we began, by saying that, although we admit the facts of production are not yet conclusively explained, we maintain that there is, to say the least, much more of direct experimental proof of the soil than of the atmospheric source of the nitrogen. Moreover, we submit that this may be said, not only of the source of the nitrogen of the cereals, but also of that of the root-crops, and of the Leguminosæ.

If, on the other hand, the atmosphere is the main, if not the exclusive, source of the nitrogen of the Leguminosæ, we would ask here, as we have asked elsewhere—why those leguminous crops which take up the most nitrogen can be less frequently grown on the same soil? Why we entirely failed to grow clover successively on ordinary arable land, which was nevertheless in a condition to yield fairly good cereal crops? Why the only condition under which we have been able to grow clover continuously was where the soil was very much richer in nitrogen (and of course in other constituents also) than the arable land? And lastly, why its growth under such circumstances has been accompanied by a rapid diminution in the amount of nitrogen in the soil, and with this a marked decline in the produce?

It will not for a moment be supposed that because in the foregoing

a soil must be largely measured by t
and the degree in which it become
not the soil a "mine," as well as a l

In this connection, speaking he
appropriate to conclude with a bri
data at our command will permit, t
racteristic difference between a larg
recently, or even not yet, broken up
which have been long under arabl
Atlantic.

A sample of Illinois Prairie soil
(now Sir) James Caird, and subm
Voelcker, to whom we are indebted
results, but also for a sample of
identical results in the two laborator
nitrogen. We have no special hist
the depth to which it was taken; b
the sample supplied to us was a mi
supplied to him, and that in the se
per cent. of nitrogen.

During the present year (1882), b
soil from the North-west Territory,
nipeg and the Rocky Mountains, we

No. 2 is from the Saskatchewan district, about 140 miles from Winnipeg, and has probably been under cultivation a shorter time than No. 1. The dry mould contained 0·3027 per cent. of nitrogen.

No. 3 is from a spot about 40 miles from Fort Ellis, and may be considered a virgin soil. The dry mould contained 0·2500 per cent. of nitrogen.

In general terms it may be said that these Illinois and North-west Territory Prairie soils are about twice as rich in nitrogen as the average of the Rothamsted arable surface soils; and, so far as can be judged, they are probably about twice as rich as the average of arable soils in Great Britain. They indeed correspond in their amount of nitrogen very closely with the surface soils of our permanent pasture land. As their nitrogen has its source in the accumulation from ages of natural vegetation, with little or no removal, it is to be supposed that, as a rule, there will not be a relative deficiency of the necessary mineral constituents.* Surely, then, these new soils are "mines" as well as laboratories? If not, what is the meaning of the term *a fertile soil?*

Assuming these soils not to be deficient in the necessary mineral supplies, and that they yield up annually in an available condition an amount of nitrogen at all corresponding to their richness in that constituent, it may be asked—whether they should not yield a higher average produce of wheat per acre than they are reported to do?

The exhausted experimental wheat field at Rothamsted, the surface soil of which at the commencement of the experiments thirty-nine years ago probably contained only about half as high a percentage of nitrogen as the average of these four American soils, yielded over the first eight years $17\frac{1}{2}$; over the next fifteen years, $15\frac{1}{4}$; over the last fifteen years (including several very bad seasons), only $11\frac{1}{8}$ bushels; and over the whole thirty-eight years about 14 bushels per acre per annum.

So far as we are informed, the comparatively low average yield of the rich North-west soils is partly due to vicissitudes of climate, partly to defective cultivation, but partly, also, to the luxuriant growth of weeds, which neither the time at command for cultivation, nor the amount of labour available, render it easy to keep down. Then, again, in some cases, the straw of the grain crops is burnt, and manure is not returned to the land. Still, if there be any truth in the

* Since the above was in type, we have seen Dr. Voelcker's report on the Illinois Prairie soil above referred to, and find he called attention to its richness in potash and other mineral constituents. He also called attention to the much higher percentage of nitrogen in it than in the soils of this country which he and others had analysed.

views we have advocated, it would seem it should be an object of consideration to lessen, as far as practicable, the waste of fertility of these now rich soils. At the same time it is obvious that, with land cheap and labour dear, the desirable object of bringing these vast areas under profitable cultivation cannot be attained without some sacrifice of their fertility in the first instance, which can only be lessened as population increases.

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CONTRIBUTION TO THE CHEMISTRY OF "FAIRY RINGS."

BY

SIR J. B. LAWES, BART., LL.D., F.R.S., J. H. GILBERT, PH.D., F.R.S., AND R. WARINGTON.

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circles of dark-green grass which frequently occur on pasture , and have long been known by the name of "Fairy Rings," naturally attracted the attention of botanists and vegetable iologists, and various explanations of their occurrence have given. It has long been supposed that the luxuriant growth rass constituting the ring is connected with the growth and decay ıngi, which so serve as manure for the grasses which succeed ı. Among the numerous explanations of the fact that the growth mes the form of an extending ring, perhaps the one which for e time received the greatest attention, was that based on the theory)ecandolle, according to which the excretions of a plant are preju- al to the growth of plants of the same description. It was sup- ed that the excretions of fungi were detrimental to their recurrence the same spot, and hence they developed only externally to the ring their previous growth.

Che first explanation of the luxuriant growth of the rings, put ward from a more purely chemical point of view, was that of Pro- sor Way, in a paper "On the Fairy Rings of Pasture, as illustrat- the use of Inorganic Manures," which was read in the Chemical tion of the British Association at Southampton in 1846, and was)lished in the *Journal of the Royal Agricultural Society of England*, 549. He analysed the ash of some of the fungi, and also of the ss of a fairy ring. From the results of these analyses he explains growth of the fairy rings as follows:—"A fungus is developed on ingle spot of ground, sheds its seed, and dies. On the spot where rew it leaves a valuable manuring of phosphoric acid and alkalis, ıe magnesia, and a little sulphate of lime. Another fungus might loubtedly grow on the same spot again; but upon the death of the ; the ground becomes occupied by a vigorous crop of grass, rising a phœnix, on the *ashes* of its predecessor." The growth of the ıs as an extending ring, and not as a disc, he further explains by fact of the removal of the grass, and with it "the greater part of inorganic materials which the fungus had collected." He adds, the nitrogen of the fungus must not be left out of consideration, that he believes—"it is to the inorganic elements that the effect is ly to be ascribed."

uckman, on the other hand, whilst admitting that fungi are fre-

b 2

quently found on or just outside the ring, considers their occurrence by no means essential to the formation of the ring, and that it may be produced by any cause unfavourable to the growth of a circular disc of grass. At the same time he says—"there is reason to think that rings to which the fungi have not become attached soon break up" (*Veterinarian*, May and June, 1870).

Almost from the commencement of the Rothamsted experiments the circumstances of the development of fairy rings have been observed with much interest, as affording a striking example of what may be called "natural rotation." It was thought that if the source of the nitrogen of the fungi growing in fairy rings were determined, some light might perhaps be thrown on the source of the nitrogen of the Leguminosæ, which are grown separately, in rotation with the cereals and other crops, or in association with the grasses in the mixed herbage of grass land. In a Rothamsted paper in 1851 (*Jour. Roy. Ag. Soc.*, **12**, 32), the subject was referred to as follows:—"A beautiful illustration of the dependence for luxuriant growth of one plant upon another of different habits, such as we have shown above, may be found in the case of the 'fairy rings,' where the fungus, by virtue of its extraordinary power of rapidly accumulating nitrogen from the atmosphere during its growth, taking up the minerals which the grasses, from their more limited power in this respect could not appropriate, provides an abundance of the nitrogenous manure so effective in the growth of the grasses which are observed to spring up with great luxuriance wherever the fungus has grown or fallen."

Here, then, it was assumed that it was the nitrogen, rather than the ash-constituents of the fungus, to which the manuring action was mainly to be attributed. Even at that time the characteristic effects of mineral and nitrogenous manures respectively, on the growth of gramineous crops, were sufficiently established by field experiments to leave no doubt that the dark colour and the luxuriant growth of the grasses on the rings were intimately connected with a liberal supply of nitrogen as manure. But it will be observed that the source of the nitrogen of the fungi was then supposed to be the atmosphere.

Since that time much directly experimental and other evidence has been acquired as to the sources of the nitrogen of green-leaved plants; and, although absolute proof is still wanting on some points—and it might well be that plants of such opposite characters as fungi might have a different source—yet doubt as to the atmospheric source of their nitrogen gradually increased. Accordingly, in 1874, an attempt was made to obtain direct experimental data on the subject. Samples of soil were taken of a fixed area and to a fixed depth within or outside a fairy ring;

The results showed the lowest percentage of nitrogen in the surface soil within the ring, a higher percentage under the ring, and a higher still outside it. The obvious conclusion was, that the soil within the ring had lost nitrogen by the growth of the fungi, and the subsequent luxuriant growth and removal of the grasses. But so important a conclusion required confirmation. Accordingly, in a short paper by one of us entitled "Note on the Occurrence of Fairy Rings," published in 1875 (*Jour. Linn. Soc. Bot.*, **15**, 17), the general indication only was stated, reserving the publication of the numerical results until they should be confirmed. The soils of other fairy rings have since been collected and investigated, and it was intended to extend the inquiry further; but, owing to the unfavourable weather of the last few years, the rings which had been under examination have disappeared. Under these circumstances, and as the general bearing of the results already obtained is unmistakable, it has been decided to put on record both the earlier and the later results, without waiting for further repetition or extension.

Before entering upon a consideration of the experimental results in question, it will be well to refer a little more in detail to some of the circumstances of the occurrence of a fairy ring.

It is probable that the fungi growing on grass land owe their occurrence, in the first instance, to the accidental droppings of animals (or birds); and it seems to depend on the conditions of soil, season, and association, whether the growth is limited to the original spot, or whether it extends, and an annually increasing ring is formed. If the soil be rich, or highly manured, or the season very favourable for luxuriance of the general herbage, the probability is that the fungi will not be reproduced, and a patch only will be developed. It is under opposite conditions, that is, where the soil is poor, that the development of rings is generally observed.

The growth of fungi being once established from some extraneous cause, such as above referred to, they will on decay supply a rich nitrogenous and mineral manuring to the adjacent herbage. A patch of dark-green luxuriant grass succeeds. This being cut or eaten off, the soil becomes the more exhausted the more luxuriant has been the growth. Accordingly the vegetation within the ring is generally less luxuriant than that outside it. In the case of mere patches, some examinations of the soil in spring and autumn have not shown a marked development of mycelium. But on digging into the turf immediately outside a ring, it is generally found penetrated by a white cobweb-like mycelium, extending to a depth of several inches, and sometimes even to a foot or more. When the mycelium is abundant, the soil is remarkably dry, and can with difficulty be wetted, as if it were greasy. The mycelium is most abundant in the soil

just outside the ring, or at the outer edge of it. If the season be favourable, an aboveground growth of fungi will appear in the spring or autumn. These fructify, and, by scattering their spores, give rise to a further growth of mycelium. The fungus thus spreads into fresh ground, and the rings extend outwards, so long as the circumstances of the soil and season are favourable. Sometimes, however, fungi are found growing in the midst of the band of luxuriant grass. In such cases it would appear that the increased growth of the grass is due to the decay of the mycelium, or of the products of its action on some of the organic compounds in the soil.

In the paper above referred to, the relative development of fairy rings, and of fungi generally, on the differently manured plots of meadow land in the park at Rothamsted is described. Among the more than twenty differently manured plots, fairy rings have occurred on only two, neither of which has received either nitrogen or potash as manure for many years. The one is annually manured with superphosphate of lime alone, and the other with a mixture of superphosphate and the sulphates of sodium and magnesium. Quite consistently with what is commonly recognised as to the conditions most favourable for the development of fairy rings, the general vegetation on these plots is of a very restricted character. Where nitrogenous manures are applied, and the luxuriant growth of the grasses is thereby promoted, no fairy rings have occurred, and the appearance of fungi is rare. As fairy rings thus developed only where the growth of the grasses and their associates was extremely limited (owing to deficient supply of nitrogen, or of potash, or of both, in a condition available to them), the questions were suggested—How far the fungi prevail simply in virtue of the absence of adverse and vigorous competition? —whether they live to a greater or less extent as parasites, and so at the expense of the sluggish underground growth of the plants in association with them? —whether they have the power of acquiring nitrogen in some form from the atmosphere?—or, lastly, whether they assimilate nitrogen from the soil itself, existing there in a condition not available to the plants growing in association with them?

Of the composition of the mycelium but little is known, and it is to be supposed that it would vary considerably at different periods of its development. On several occasions it has been found at Rothamsted to leave a very considerable incombustible residue, consisting chiefly of calcium carbonate, which is presumably the result of the destruction of calcium oxalate.

The general composition of the aboveground growth has been determined by Fleury in the case of two of the fairy ring fungi (*Rép. Pharm.*, 31, ann. 73, p. 261). The following is an abstract of his results:—

TABLE I.—*Percentage Composition of two Fairy Ring Fungi.*

Species.	Water.	Nitrogen reckoned as albuminoïds.	Fatty matter.	Soluble carbohydrates.	Fibre.	Ash.
			In Fresh Substance.			
Marasmius oreadum	91·75	2·93	0·19	3·59	0·67	0·87
Agaricus prunulus..	89·25	4·11	0·14	4·08	0·81	1·61
			In Dry Matter.			
Marasmius oreadum	—	35·57	2·40	43·34	8·12	10·57
Agaricus prunulus..	—	38·32	1·38	37·77	7·53	15·00

The following is the composition of the ash of one species of fairy-ring fungus as determined by Professor Way (*Jour. Roy. Ag. Soc.*, **7**, 550, 1846):—

TABLE II.—*Percentage Composition of the Ash of* Agaricus prunulus.

Ash in 100 dry.	Per cent. in Ash.								
	K_2O.	Na_2O.	CaO.	MgO.	P_2O_5.	SO_3.	SiO_2.	Cl.	CO_2.
6·38	55·10	3·54	1·35	2·20	29·49	1·93	1·09	0·25	3·80

The composition of the fairy ring fungi appears from these analyses to be very similar to that of other fungi which have been analysed; and it may be mentioned that one of the species examined by Fleury, the *Marasmius oreadum*, occurs on the rings at Rothamsted. The fungi contain a large proportion of nitrogenous matter, amounting to more than one-third of their dry substance; and their ash is extremely rich in both potash and phosphoric acid, but especially in potash. Yet it will be remembered that fairy rings developed only on two of the experimental plots at Rothamsted, neither of which had received either nitrogen or potash as manure for many years, and where the growth of the grasses was extremely meagre.

It is evident from the very restricted vegetation of these plots, from the richness in nitrogen of the fungi, and from the great luxuriance of the grasses which succeed them, that the fungi were

able to obtain an amount of nitrogen from some source greatly in excess of that which was available to the associated herbage. What is the source of this nitrogen? Has the fungus the power of assimilating it largely from the atmosphere? or has it the power of taking it up from the soil in a manner, or in a degree, which the grasses and other green-leaved plants do not possess? The object of the experiments now to be described was to obtain an answer to these questions.

We will first give a brief history of the various samples of soil which have been collected and analysed, and afterwards direct attention to the results which have been obtained.

The Grove Paddock Fairy Ring.

The samples of soil were taken on May 19th, 1874. The ring, which then consisted of a half circle several yards in diameter, and had been observed to increase during the past few years, was near a hedge and some trees, and the soil was much permeated by roots. The band of grass forming the ring was about 2 feet wide, and of a dark bluish-green colour. The grass was of a much lighter colour both within and outside the ring, and rather lighter within than outside. Samples of the soil were taken at three points: 1. Two feet within the ring. 2. In the centre of the ring-band. 3. Two feet outside the ring. In each case a sample of the first, and of the second 9 inches of depth, was taken.

The mode of collecting the soil samples was that which has been employed for many years at Rothamsted. A frame of strong sheet iron 6 inches square, 9 inches deep, open at the top and bottom, and having a strong rim outside the upper edge, was driven into the ground until the upper edge was level with the surface. The contents were then carefully taken out, and constituted the sample of the first 9 inches of depth. The soil round the frame was then removed to the depth of its lower edge, it was again driven down into the soil, and the contents taken out, these representing the second 9 inches of depth.

The sample of the first 9 inches of soil taken on the ring was remarkably dry, and much paler in colour than that of the sample from the same depth either from without or within the ring, that from outside the ring being much the darkest of the three. Mycelium was found to extend to the depth of a foot or more. This is a somewhat greater depth than usual, probably accounted for by the large amount of organic *débris* from the roots of the hedge, and two large ash trees, one on either side.

The Broadbalk Field Fairy Ring.

This was a small imperfect ring forming about two-thirds of a

circle. The ground within the circle had been disturbed in recent years, and there was doubt how far the disturbance had extended.

The first series of samples was taken on June 18th, 1877. The ring was then covered with a luxuriant growth of grass, interspersed with which were a few fungi. The samples of soil taken were: 1. Within the ring, about 14 inches from it. 2. On the ring. 3. Just outside the ring. 4. Quite outside it, about 16 inches from it. A rather considerable amount of mycelium was found in the soil taken from the ring, extending from the surface to a depth of 5 or 6 inches. In the sample taken just outside the circle a little mycelium was found.

A second series of samples was taken on September 15th of the same year. The ring had widened since June, and was again covered with a luxuriant growth of grass. The samples taken were: 1. Within the ring, 18 inches from it. 2. On the ring. 3. Outside the ring, about 15 inches from it. The soil from the ring contained a comparatively small amount of mycelium, extending about 4 inches from the surface.

The samples of soil from this ring, and from those subsequently experimented upon, were not taken with the iron frame already described, but with a steel cylinder, $2\frac{1}{2}$ inches in diameter, and 12 inches long, fixed at the end of a stout iron rod. The cylinder was driven into the ground until its upper edge was level with the surface; when withdrawn it contained a solid core of soil, which was removed through a slit in the side which was covered during the working. The advantage of this mode of soil sampling is its simplicity; but the objections to it are that the quantities of soil brought up are more irregular, and do not therefore so nearly represent the depth intended as when the wider square frame is used. Owing to the narrowness of the cylinder the soil rises within it with considerable difficulty, becoming much consolidated below, and when the cylinder is drawn up it is found to be but partially filled. In any case, however, it would be inappropriate to calculate quantities of soil, or of any of its constituents, over a given area to a given depth, from single samples; and as the object in the present instance was simply to compare the percentage composition of different samples of soil collected at the same time and in the same manner, the imperfections of the method above referred to are of less consequence.

The Park Fairy Rings.

It has been already mentioned that fairy rings were numerous on the plot of experimental meadow land in the park which was continuously manured with superphosphate of lime alone. A perfect ring on this plot was selected for examination. The samples of soil

ably in width, and its outline having become indi[illegible] samples were taken from it; but another partial ring [illegible] was selected for experiment. The soil of this second rin[illegible] on April 25th, 1878. The band was then about 2 f[illegible] samples taken were: 1. Within the ring, about 2½ feet [illegible] the ring towards the inside. 3. On the ring towards the [illegible] side the ring, about 1½ foot from it. In the soil take[illegible] towards the outside of it, mycelium was fairly [illegible] extended 5 or 6 inches below the surface. Here the[illegible] and of a lighter colour, than at the other points.

Preparation and Analysis of the Soil Samp[illegible]

From all the samples, the stones, roots, and other ob[illegible] residue were carefully picked out, and the remaining [illegible] to fine powder. The samples from the Broadbalk Fiel[illegible] Fairy Rings were partially dried by exposure in a thin [illegible] room immediately after being received in the laborat[illegible] from the Grove Paddock were not so prepared. As a [illegible] of calculation, especially of the percentage of water, [illegible] the fresh samples, and of their separated parts, were ta[illegible] excepting those of the soils from the Broadbalk Field. [illegible]

The following table shows the percentage of water [illegible] at 100° C., and calculated on the total fresh soil ([illegible] the cases of all the

TABLE III.—*Percentage of Water in Fresh Soil as collected, exclusive of Stones.*

	Surface soil.	Subsoil.
Grove Paddock Fairy Ring Soils, May 19, 1874.		
Within the ring..............	16·03	15·68
On the ring	12·58	12·30
Outside the ring	15·71	16·24
The Park Fairy Ring Soils, September 19, 1877.		
Within the ring..............	22·80	17·04
On ring (centre)	19·29	13·13
On ring (outer edge)	18·50	13·23
Just outside ring	23·33	15·03
The Park Fairy Ring Soils, April 25, 1878.		
Within the ring..............	26·34	19·21
On ring (inside)	26·33	—
On ring (outside)	21·95	19·14
Outside the ring	27·96	19·74

It will be observed that the percentage of water is almost uniformly lower in the soils taken from the ring-band than in those taken either within or outside it; and this generally holds good in the case of the subsoils as well as of the surface soils. The comparative dryness of the soil under the ring-band will in part be due to the greater evaporation incident to the greater activity of growth; but, in some cases, as in that of the Grove Paddock Ring, it is probably to be largely attributed to the action of the underground fungoid growth in giving to the soil, in some way not quite explicable, a power of resisting the free absorption of water, as if it were greasy, as already referred to.

In all the surface soils the nitrogen has been determined by combustion with soda-lime, and the carbon by combustion in oxygen; and in those from the Broadbalk Field and the Park Fairy Rings the nitrogen as nitric acid has also been determined. The subsoils have only been partially examined, and such determinations of nitrogen as have been made in them by the soda-lime method indicate that the variations in the amount are due to differences in the character of the subsoils, quite independent of the influences of the growth of the

fungi, and of the grasses succeeding them, which are the subjects of the present inquiry. Indeed, very numerous determinations of nitrogen in subsoils have shown that, with a low actual percentage, the variations in the amount in different samples are proportionally great, and obviously to a great extent unconnected with the special history of the plot from which the samples are taken. Moreover, so far as the total nitrogen and carbon are concerned, it seems probable that the influences of the fairy ring growth are, to a great extent, if not wholly, limited to the surface soils; and it will be seen that the results relating to them afford conclusive evidence on the points under inquiry.

In Table IV are given the percentages of nitrogen and carbon in the dry fine surface soils (that is excluding stones, roots, and water).

TABLE IV.—*Percentages of Nitrogen and Carbon in the Dry Fine Surface Soils.*

	Nitrogen.	Carbon.
Grove Paddock Fairy Ring Soils, May 19, 1874.		
Within the ring	0·262	3·06
On the ring	0·274	(2·72)*
Outside the ring	0·287	3·34
Broadbalk Field Fairy Ring Soils, June 18, 1877.		
Within the ring	0·271	2·38
On the ring	0·300	3·36
Just outside the ring	0·327	3·05
Quite outside the ring	0·303	3·52
Broadbalk Field Fairy Ring Soils, September 15, 1877.		
Within the ring	0·226	2·48
On the ring	0·244	2·60
Outside the ring	0·274	3·12

* In the Grove Paddock soils the carbon was not determined until some years after the collection, when the sample taken on the ring was found to have a high percentage of water, and a mouldy odour; it had doubtless lost carbon.

	Nitrogen.	Carbon.
The Park Fairy Ring Soils, September 19, 1877.		
Within the ring	0·222	2·88
On the ring (centre)	0·230	3·01
On the ring (outer edge)	0·276	3·40
Just outside the ring	0·259	3·31
The Park Fairy Ring Soils, April 25, 1878.		
Within the ring	0·253	3·12
On the ring (inner side)........	0·245	2·97
On the ring (outer side)	0·268	3·11
Outside the ring	0·269	3·44

Although, as has been said, all visible organic *débris* was carefully removed from the samples before nitrogen and carbon were determined in them, it will be readily understood that in the case of surface soils of grass land containing so much of such matter, it is extremely difficult to exclude the whole of it, whilst any irregularity in this respect will affect the amount of carbon more than that of the nitrogen; and a consideration of the results in detail leads to the conclusion that the carbon determinations are, from this cause, less trustworthy than those of the nitrogen. Still a glance at the Table (IV) shows that in each of the five series of samples the percentage of both nitrogen and carbon is much lower in the soils within the ring than outside it; that is to say, it is much lower where the action of the fungus and the growth and removal of the luxuriant crop of grass is past, than where the fungus has not yet been developed. In most cases where the action of the fungus is still in progress, the percentages of nitrogen and carbon are intermediate between those in the soils within and without the circle. The spread of the ring is in fact marked by a destruction of organic matter containing nitrogen and carbon.

It will be observed, however, that there are some apparent anomalies in the results, but on an examination of the circumstances of the experiments, these are sufficiently explained. Thus, the percentages of both nitrogen and carbon are much higher in the series of samples collected from the Broadbalk Field Fairy Ring in June, 1877, than in those collected from the same ring in the following September; and according to notes taken at the time, the sampling cylinder did not bring up so much soil in June as in September. In other words,

the samples taken in June comprised a larger proportion of the surface, and a smaller proportion of the subsoil, and hence the higher range in the percentage of nitrogen and carbon in them. Again, the percentages of both nitrogen and carbon are abnormally high in the sample from the Park Fairy Ring collected at the outer edge in September, 1877, and in the samples collected within the ring, and on the outer side of it, in April, 1878. In these cases also the cylinder brought up relatively small weights of soil, and hence the samples consisted in a relatively large proportion of surface soil, and showed accordingly higher percentages of nitrogen and carbon.

The general bearing of the results is unmistakably shown in the next table (V), in which, assuming each ring to be made up of the three divisions of " within," " on," and " outside," the results for each such division of the five different series of samples are brought together, and the mean taken. Thus, we have the mean of all the determinations on the samples taken within the ring, the mean of all those taken on the ring, and of all those taken outside it. At the foot of the table there is given the mean amount of nitrogen and carbon in the soils within, and on the ring, compared with that outside it taken as 100. There is also given the mean proportion of carbon to 1 of nitrogen in the soils taken at the different positions.

TABLE V.—*Mean Percentages of Nitrogen and Carbon in the Fine Dry Fairy Ring Soils.*

Description of ring.	Nitrogen per cent.			Carbon per cent.		
	Within the ring.	On the ring.	Outside the ring.	Within the ring.	On the ring.	Outside the ring.
Grove Paddock (May, 1874) ..	0·262	0·274	0·287	3·06	2·72	3·34
Broadbalk (June, 1877)	0·271	0·300	0·315	2·38	3·36	3·29
" (September, 1877) ..	0·226	0·244	0·274	2·48	2·60	3·12
Park (September, 1877)	0·222	0·253	0·259	2·88	3·21	3·31
" (April, 1878)............	0·253	0·257	0·269	3·12	3·04	3·44
Mean	0·247	0·266	0·281	2·78	2·99	3·30
N and C "outside" = 100	87·9	94·7	100	84·2	90·6	100
Carbon to 1 nitrogen..........	—	—	—	11·3	11·2	11·7

The results brought together in this way clearly bring to view the fact that in each of the five series of experiments the percentage of

nitrogen was the highest in the soil outside the ring, and the lowest in that within the ring. It was also in each case in intermediate amount in the soil on the ring. For the reasons already explained, the carbon results are not so trustworthy as those of the nitrogen. Still, the percentage of carbon is likewise in every case very much higher outside than within the ring; and it is, on the average, in intermediate amount on the ring. The general indications of the mean results may thus be safely relied upon. From these the conclusion already drawn from a study of the details becomes the more obvious, namely, that the growth of the fungus and the subsequent increased growth and removal of the associated herbage is accompanied by a considerable reduction in the amount of the organic nitrogen and carbon in the soil. Since prior to the growth of the fungus, that of the surrounding herbage was extremely restricted, and it became luxuriant only after the growth of the fungus, it cannot be doubted that it is primarily to its action that the reduction of the nitrogen and carbon in the soil is to be attributed. In other words, the fungi have taken up from the soil organic nitrogen and carbon that were not available to the previously established vegetation.

From the figures in the last line but one in the table, it is seen that reckoning the amount of nitrogen and carbon respectively outside the ring as 100, that of the carbon has been reduced in a greater proportion than that of the nitrogen, both on and within the ring. Accordingly the last line in the table shows that there was a higher proportion of carbon to nitrogen in the soil outside the ring than in that either on or within the ring. Calculation also shows that the proportion of carbon to that of the nitrogen lost by the soil is greater up to the stage of the active growth of the ring than afterwards; that is, the proportional loss of carbon is the greater under the more immediate influence of the growth of the fungus, and that of the nitrogen is the greater subsequently. Further, the relation of carbon to nitrogen is very much higher in the soil than it would be in the dry matter of the fungus. The action of the mycelium is therefore not only to reduce the carbon in a greater proportion than the nitrogen of the soil, but to do so in a much greater degree in proportion to the amount assimilated, a portion of the carbon being doubtless exhaled as carbonic acid. It is true that the proportion of carbon to nitrogen is much higher in the grasses which succeed the fungi than in the soil; but it is known that green-leaved plants generally, and grasses especially, derive most, if not all, of their carbon from the atmosphere.

Although the experiments do not supply data for exact calculation on the point, it may be stated, in general terms, that the mean results would represent a loss by the surface soil of several hundred pounds of nitrogen, and of several thousand pounds of carbon, per acre, by the

action of the fungus, and the subsequent luxuriant growth and removal of the grasses.

It was certainly to be expected that nitrates would be formed in considerable quantity on the decay of the fungus (whether in the stage of mycelium or of more advanced development), and possibly also on that of residual products of the action of the mycelium on the nitrogenous organic matter of the soil. It is quite in accordance with the supposition that nitrates are formed, that the band of grass following the track of the fungus should have the dark green colour which characterises it. It is, however, difficult to trace the formation of nitrates in meadow land, or at any rate to determine the quantity in which they are produced, as, owing to the amount and activity of the vegetation, they are for the most part taken up as soon as they are formed. Nevertheless, determinations of nitrates were attempted in the cases of the Broadbalk Field and of the Park Fairy Ring soils. The Crum-Frankland method was the one then in use, and was the one adopted. The soil extracts were purified by alcohol, but the chlorides were removed by silver. Under these circumstances the attack on the mercury was very feeble, and the nitrates present were undoubtedly under-estimated. The Broadbalk soils of the second collection have since been analysed by Schlösing's method, which is more accurate in the case of such extracts. The results of the determinations are given in Table VI below.

TABLE VI.—*Nitrogen as Nitrates per Million of Dry Fine Soil.*

	Crum-Frankland method.	Schlösing method.
Broadbalk Fairy Ring Soils, collected June 18, 1877.		
Within the ring	0·23	—
On the ring	0·92	—
Just outside the ring	0·43	—
Outside the ring	0·09	—
Broadbalk Fairy Ring Soils, collected September 15, 1877.		
Within the ring	1·31	1·03
On the ring	8·07	11·46
Outside the ring	1·10	2·44

	Crum-Frankland method.	Schlösing method.
The Park Fairy Ring Soils, collected September 19, 1877.		
Within the ring	trace	—
On the ring (centre)	0·46	—
On the ring (outer edge)	1·21	—
Just outside the ring	trace	—
The Park Fairy Ring Soils, collected April 25, 1878.		
Within the ring	0·17	—
On the ring (inner side)	1·21	—
On the ring (outer side)	none	—
Outside the ring	0·18	—

It will be seen that in the case of the second series of samples from the Broadbalk Field Ring, there was a very considerable amount of nitric acid in the soil of the ring-band. In all other cases the quantity, if any, was very small. It was, however, always more abundant in the soil of the ring-band than either within or without the circle.

In making the extracts of the surface soils for the determination of nitrates, it was observed that when mycelium was present, the watery extract was dark-coloured, and gave a bulky organic residue on evaporation. It is to be supposed, therefore, that some of the products of the decay of the mycelium, or of the action of the mycelium on the soil, will pass by drainage into the subsoil.

Some of the subsoils were examined for nitric acid, but scarcely more than a trace was found, excepting in the subsoil collected under the ring-band at the second sampling of the Broadbalk Field Ring soils, where the table shows the highest amount in the surface soils. Even here, however, the nitrogen as nitrates in the subsoil amounted to only 0·82 per million of the dry soil.

On a review of the whole of the results of our examinations of the soils of fairy rings, we think there can be no doubt that the source of the nitrogen of the fairy ring fungi is the organic nitrogen of the soil itself, which it assimilates, presumably, though not certainly, as organic nitrogen, and eventually deposits as manure which becomes available to the associated herbage. Further, the whole of the phenomena of the fairy rings, so far as the nitrogen is concerned, are thus explained without supposing any intervention of atmospheric nitrogen.

Evidence is still wanting to prove whether at all, or in what degree,

some green-leaved plants have a power of assimilating the organic nitrogen of the soil, such as is possessed by the fungi. That Leguminosæ, for example, will take up more nitrogen from an arable soil than Gramineæ would from the same soil is certain. In some cases part, if not the whole, of the increased assimilation of nitrogen by the Leguminosæ is doubtless due to the arrest of nitrates that would have been lost by drainage in the case of the growth of Gramineæ. In others, the evidence at command does not justify the conclusion that the whole of the increased amount can be so accounted for. Again, under the influence of potassium salts applied as manure, leguminous plants will take up a considerably increased amount of nitrogen, even from a poor arable soil; whilst under the same conditions a gramineous crop would not do so. This action is very marked when potash salts are applied to grass land. In this case, however, the percentage of nitrogen in the much richer surface soil is reduced in a degree easily determinable by the soda-lime method. The question arises, therefore, how far the increased amount of nitrogen taken up under these circumstances, is due to a liberation of soil-nitrogen independently of any direct action of the plant itself; or whether, under the influence of the potash supply, the plant acquires a character, or increased activity, of underground growth, by virtue of which it is enabled to take up the organic nitrogen of the soil in a manner, or in a degree, of which it is not otherwise capable? Some Leguminosæ, however, which have very deeply distributed roots, have the power of assimilating very large amounts of nitrogen over a given area, when growing on arable soil with the surface impoverished, and the subsoil naturally poor, so far as nitrogen is concerned.

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NEW DETERMINATIONS

OF

AMMONIA, CHLORINE, AND SULPHURIC ACID,

IN THE

RAIN-WATER

COLLECTED AT ROTHAMSTED.

BY

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CONTENTS.

IN a Report recently made in this 'Journal,' "On the Amount and Composition of the Rain and Drainage-Waters collected at Rothamsted" (vol. xvii., 1881, p. 241), an account was given of various investigations on the composition of the rain-water collected in the large rain-gauge at Rothamsted. These investigations embraced determinations of ammonia made at Rothamsted in 1853–4; determinations of ammonia and nitric acid by Professor Way in the rain of 1855 and 1856; determinations of total solid matter, hardness, organic carbon and nitrogen, ammonia, nitric acid, and chlorine, made by Dr. Frankland in samples of rain collected in 1869–70; and lastly, determinations of chlorine made at Rothamsted in 1877–80. We have now to give a further account of work carried on in the same direction.

THE AMMONIA IN RAIN.

It will be recollected that a considerable difference was shown to exist between the results of the earlier and later determinations of ammonia. The earliest Rothamsted determinations,

made on the rainfall of fifteen months, 1853–4, showed a mean of 0·74 of nitrogen existing as ammonia per million of rain-water. Way's determinations on the rain of two years, 1855 and 1856, gave a mean of 1·03 of nitrogen as ammonia per million. The later determinations by Frankland gave, on the other hand, 0·37 of nitrogen as ammonia per million of rain, as the numerical mean of 69 analyses, excluding dew. Indeed, if the mean be calculated from Frankland's 56 analyses of rainfalls of which the quantity was known, the nitrogen as ammonia in a mixture of these rainfalls will amount to only 0·318 per million.

In discussing these discrepant results it was stated that the method used in the earlier determinations of ammonia at Rothamsted, and also that by Professor Way, were probably liable to error on the side of excess. It appeared desirable, therefore, to determine the ammonia in a new series of samples of rain-water by the application of modern methods. In the final conclusions, printed at the close of the Report (this 'Journal,' 1882, p. 66), it was stated that some new determinations of ammonia had already been made at Rothamsted, the results of which were generally accordant with those of Dr. Frankland.

The new determinations of ammonia in rain which we now have to report, include—1. A series of determinations in the rainfall of each day (if any), from June 22, 1881, to January 5, 1882; 2. A series of determinations in mixed samples of rain, each representing the rainfall of a whole month.

1. *Ammonia in Daily Rainfalls.*—During the period of this investigation nearly every sample of water collected in the large rain-gauge (area $\frac{1}{1000}$th of an acre) was submitted to analysis, the ammonia being determined either on the day of collection, or within at most two or three days of this date.

The ammonia was determined in all cases by Nessler's well-known method. Each sample of rain was treated in the first place with Nessler solution, for the purpose of ascertaining what quantity it would be convenient to distil. The volume of rain taken for the actual experiment was varied, so as in all cases to yield ammonia equal to nearly 2 cubic centimeters of the standard solution of chloride of ammonium, the unavoidable errors in the final comparison of tint being least at this point. The measured volume of rain was then added to the contents of the retort, previously freed from ammonia by boiling; the whole volume in the retort never exceeded 600 cubic centimeters. The water in the retort always contained a little carbonate of sodium. The inner tube of the Liebig's condenser employed had a diameter of about ½ inch; [illegible]

of copper, 30 inches in length. In every case 150 cubic centimeters of water were distilled, and one determination of ammonia made in the whole distillate.

The results yielded by these analyses of daily rainfall will be found in Table I. (p. 6). The rain (or other aqueous deposit) was collected at 9.30 A.M. Falls of snow are distinguished by an "*s*," hoar-frost by an "*f*;" most of the very small deposits represent dew. The observations upon the direction of the wind, made at the hour of collection, are also recorded in the Table. Nearly the whole of the determinations of ammonia were made by the late Mr. W. H. A. Peake.

These daily rainfalls exhibit an enormous variation in the proportion of ammonia present, the quantity ranging from 0·043 of nitrogen per million, found in a rainfall of 0·713 inch on November 27, after two preceding days of heavy rain, to 5·49 per million in the case of a deposit of dew, amounting to 0·007 inch, occurring on September 17, after a considerable interval of dry weather. One condition which very largely determines the proportion of ammonia present is undoubtedly the quantity of the rainfall; with increasing quantities of rain the proportion of ammonia always tends to diminish. This is best shown in Table II. (p. 9), in which the whole of the daily rainfalls are grouped according to quantity. Other circumstances, however, have a still greater influence on the proportion of ammonia, as is evident by a glance at the range of variation found among rainfalls of the same quantity, also shown in Table II. The chief determining factor is undoubtedly the condition of the atmosphere. If heavy rain has recently occurred, and the atmosphere has consequently been thoroughly washed, then even the smallest deposits are found to be poor in ammonia; while, on the other hand, after a considerable interval of dry weather, or small rainfall, the rain is sure to be rich in ammonia. Several examples will be found in Table I. of the gradually increasing richness of a series of small deposits occurring without any considerable amount of rain, and also of the poverty in ammonia of rain collected after previous wet weather.

In the previous Report on the Composition of the Rain at Rothamsted it was shown that the summer rainfall is on the whole distinctly richer in ammonia than the winter rainfall, and confirmatory evidence of this fact will be afforded by the analyses of the mixed monthly rainfalls to which we shall presently call attention. This difference is not, however, very marked in the case of the daily rainfalls at present under discussion. If we group these rainfalls according to quantity, as in Table II., and compare the composition of similar groups of rain occurring in the warmer months (June to September), and

TABLE I.—The DAILY RAINFALL, and the AMOUNT of NITROGEN as AMMONIA per MILLION of RAIN, from June 22, 1881, to January 5, 1882.

Date of Collection.	Rainfall, Dew, or Snow.	Nitrogen as Ammonia per Million.	Direction of Wind.
1881	Inches.		
June 22	0·023	0·350	S.
,, 23	0·061	0·329	W.
,, 25	0·001	..	S.
,, 26	0·177	0·156	S.W.
,, 27	0·015	..	S.
,, 28	0·092	0·576	W.
,, 29	0·001	..	W.
July 6	0·304	0·700	S.W.
,, 7	0·169	0·268	N.W.
,, 8	0·001	..	S.W.
,, 9	0·087	0·309	W.
,, 10	0·013	0·604	S.W.
,, 12	0·004	..	S.
,, 13	0·004	..	S.W.
,, 16	0·015	2·676	N.W.
,, 20	0·034	2·368	N.W.
,, 22	0·006	..	S.
,, 23	0·030	1·688	S.W.
,, 24	0·124	0·384	S.W.
,, 25	0·020	1·112	S.W.
,, 27	0·014	1·441	S.W.
,, 28	0·007	..	S.W.
,, 29	0·286	0·117	N.W.
,, 31	0·492	0·120	S.
Aug. 1	0·152	0·100	S.
Whole Month	1·762	0·380	
Aug. 2	0·029	0·721	N.W.
,, 5	0·004	2·141	S.
,, 9	0·923	0·104	W.
,, 10	0·006	0·824	S.W.
,, 11	0·042	0·576	S.
,, 12	0·165	0·141	S.E.
,, 13	0·600	0·166	W.
,, 14	0·026	0·247	N.W.
,, 16	0·070	0·371	S.W.
,, 17	0·090	0·257	W.
,, 18	0·245	0·120	W.
,, 19	0·302	0·103	S.E.
,, 20	0·030	0·782	S.W.
,, 22	0·285	0·453	S.W.
,, 23	0·018	1·235	E.
,, 24	0·675	0·244	S.W.
,, 25	0·094	0·313	S.
,, 26	0·615	0·131	S.W.
,, 27	0·211	0·233	W.
,, 29	0·062	0·272	S.

Date of Collection.	Rainfall, Dew, or Snow.	Nitrogen as Ammonia per Million.	Direction of Wind.
1881	Inches.		
Aug. 30	1·000	0·070	W.
,, 31	0·310	0·206	N.
Sept. 1	0·015	1·400	N.
Whole Month	5·817	0·183	
Sept. 2	0·014	0·721	N.W.
,, 3	0·012	0·947	N.W.
,, 4	0·018	0·782	N.
,, 5	0·004	..	N.E.
,, 6	0·460	0·144	S.W.
,, 7	0·098	0·247	N.W.
,, 8	0·015	0·535	S.W.
,, 11	0·017	1·153	N.
,, 12	0·024	1·071	N.W.
,, 13	0·046	0·398	S.W.
,, 14	0·007	1·235	W.
,, 15	0·004	1·482	S.E.
,, 16	0·005	1·565	W.
,, 17	0·007	5·490	S.
,, 18	0·011	3·129	S.
,, 19	0·067	0·391	S.W.
,, 20	0·007	1·976	S.E.
,, 21	0·276	0·239	E.
,, 22	0·011	0·700	W.
,, 23	0·292	0·425	N.E.
,, 25	0·737	0·098	S.W.
,, 26	0·006	0·439	S.W.
,, 27	0·005	0·885	S.W.
,, 28	0·006	0·906	N.W.
,, 29	0·008	1·647	E.
,, 30	0·007	2·635	E.
Oct. 1	0·007	2·471	N.
Whole Month	2·171	0·306	
Oct. 2	0·011	1·400	N.E.
,, 3	0·007	1·318	N.E.
,, 4	0·004	1·894	N.E.
,, 5	0·007	1·647	N.E.
,, 6	0·022	0·885	W.
,, 7	0·038	1·647	N.W.
,, 8	0·303	0·211	N.W.
,, 9	0·149	0·466	N.W.
,, 10	0·012	0·782	W.
,, 11	0·005	0·659	S.W.
,, 12	0·021	0·604	S.W.
,, 13	0·114	0·384	W.

LE I. (*continued*).—The Daily Rainfall, and the Amount of ITROGEN as Ammonia per Million of Rain, from June 22, 1881, to anuary 5, 1882.

te of ection.	Rainfall, Dew, or Snow.	Nitrogen as Ammonia per Million	Direction of Wind.
381	Inches.		
. 14	0·769	0·085	S.W.
15	0·008	..	W.
16	0·004	0·343	N.
17	0·006	0·313	E.
18	0·008	1·647	E.
20	0·004	0·659	N.E.
21	0·280	0·247	S.E.
22	0·032	1·647	E.
23	0·982	0·312	E.
24	0·150	0·214	E.
25	0·020	0·453	N.E.
26	0·029	0·329	N.E.
27	0·013	0·604	N.E.
28	0·015	0·713	N.W.
29	0·006s	0·844	N.W.
30	0·017f	0·556	N.W.
31	0·010f	0·618	S.E.
iole nth	3·046	0·307	
r. 2	0·037s	0·988	S.E.
3	0·064	0·288	S.E.
4	0·293	0·494	S.E.
5	0·137	0·181	S.W.
6	0·031	0·412	W.
7	0·011	0·467	S.E.
8	0·018	4·255	S.E.
9	0·005	4·941	S.E.
10	0·005	4·392	S.W.
12	0·060	0·321	S.W.
13	0·007	1·071	N.W.
14	0·005	1·976	N.W.
16	0·011	1·318	S.W.
17	0·432	0·124	S.W.
18	0·015f	0·535	S.
19	0·051	0·371	S.E.
20	0·041	1·235	S.W.
21	0·186	0·165	S.W.
22	0·169	0·216	S.W.
23	0·008	0·316	S.W.
24	0·035	0·288	S.W.
25	0·643	0·119	S.E.
26	0·347	0·132	S.E.
27	0·713	0·043	S.W.
28	0·006	0·115	S.W.

Date of Collection.	Rainfall, Dew, or Snow.	Nitrogen as Ammonia per Million.	Direction of Wind.
1881	Inches.		
Nov. 29	0·015f	0·247	S.W.
,, 30	0·009f	1·071	S.E.
Dec. 1	0·121	0·302	S.E.
Whole Month	3·475	0·239	
Dec. 2	0·166	0·357	S.W.
,, 3	0·022	0·508	S.E.
,, 4	0·008f	1·318	S.E.
,, 5	0·062	0·275	S.
,, 6	0·194	0·103	S.E.
,, 7	0·536	0·070	S.W.
,, 8	0·012f	0·259	S.
,, 9	0·044	0·362	W.
,, 10	0·004f	2·471	N.E.
,, 11	0·076s	0·577	N.W.
,, 12	0·110	0·494	N.W.
,, 13	0·086	0·329	N.W.
,, 14	0·011f	..	N.W.
,, 15	0·260	0·300	S.E.
,, 16	0·213	1·400	S.
,, 17	0·342	0·196	S.W.
,, 18	1·252	0·058	N.
,, 19	0·005f	0·137	S.W.
,, 20	0·366	0·099	S.W.
,, 21	0·424	0·079	S.W.
,, 22	0·007	0·309	S.W.
,, 23 / ,, 24	0·018f	1·029	N. / S.E.
,, 26	0·031	0·590	S.W.
,, 27	0·002	..	S.W.
,, 28	0·010	1·771	S.W.
,, 29	0·005	1·853	S.W.
,, 31	0·112	0·346	S.E.
1882			
Jan. 1	0·005	1·281	S.W.
Whole Month	4·383	0·230	
Jan. 2	0·184	0·118	S.W.
,, 3	0·290	0·124	S.W.
,, 4	0·013f	0·357	N.W.
,, 5	0·134	0·172	S.W.

at the same temperature
necessarily be the case, b
becomes capable of takin
spheric ammonia. The
theoretically be highest w
ture, a cold aqueous dep
atmosphere; such conditi
south to north, or when
following a warm day.

The influence which th
proportion of ammonia p
tially studied from the dat
fluence of warm and cold
already noticed as chara
winter. The smaller aq
tinctly richer in ammoni
effect is not perceptible in

Dr. Frankland had calle
tion of the rain-water from
gauge. During the prese
marks were wiped off as s
at the same time recorded.
nection between these mar
the rain. Without going i
these marks were most ab
during the whole of Sept
noticed.

TABLE II.—The AVERAGE AMOUNT of NITROGEN as AMMONIA in DAILY RAINFALLS of different QUANTITY, from June 22, 1881, to January 5, 1882.

Groups of Rainfall.	Number of Examples.	Average Quantity of each Rainfall.	Nitrogen as Ammonia, per million.		
			Average.	Highest.	Lowest.
		Inches.			
Below ·01 inch	35	0·006	1·536	5·491	0·115
From ·01 to ·02 inch	27	0·014	1·141	4·255	0·247
From ·02 to ·04 inch	19	0·028	0·924	2·368	0·247
From ·04 to ·06 inch	5	0·045	0·571	1·235	0·362
From ·06 to ·08 inch	8	0·065	0·359	0·577	0·272
From ·08 to ·10 inch	6	0·091	0·338	0·576	0·247
From ·10 to ·20 inch	18	0·151	0·232	0·494	0·100
From ·20 to ·30 inch	11	0·266	0·360	1·400	0·117
From ·30 to ·40 inch	7	0·325	0·229	0·700	0·099
From ·40 to ·70 inch	9	0·542	0·138	0·244	0·070
From ·70 to 1·00 inch	5	0·825	0·138	0·312	0·043
Above 1·00 inch	2	1·126	0·063	0·070	0·058
	152	0·142	0·248	5·491	0·043

a similar manner, unless the contrary is stated. It will be noticed that several small deposits were left unanalysed during the earlier part of the investigation. If we assume for these the composition proper to their quantity and season, the average composition of the whole rainfall from June 22 to January 5, amounting to 21·645 inches, becomes 0·254 of nitrogen as ammonia per million of water.

2. *Ammonia in Monthly Rainfalls.*—A mixed sample, representing the rainfall of each month, has been regularly prepared by placing in a carboy a fixed proportion (1 gallon for every inch) of the rainfall of each day. In June 1881 determinations of ammonia were commenced in these monthly mixtures, and have now been continued for rather more than two years, each mixture being analysed as soon as possible after the termination of the month of collection. A considerable number of monthly mixtures of rain-water, made previously to June 1881, were also analysed in this month; these samples were in many cases of considerable age when analysed. All the analyses of monthly mixtures will be found in Table III. (p. 11); the results relating to old samples are separated by a thick black line from those obtained by the analysis of fresh samples.

It is clear that the determinations in the monthly mixtures can only be of value if the ammonia originally in the rain remains unaltered till the analysis of the mixture can be made. In our former Report it was assumed that the ammonia in rain-water would diminish on keeping, that it would, in fact, pro-

bably be nitrified. We must thus in the first place consider what evidence we have as to the permanence of ammonia in the rain-water samples.

From the daily analyses of rain-water already given, the composition of the water for each month, July to December 1881, has been calculated, correction being made for the few rainfalls left unanalysed. The calculated composition of the monthly mixtures is compared below with their actual compositions when the mixture was completed; and further, with the results of an analysis of these mixtures made in December 1882.

Month (1881).	Nitrogen as Ammonia, per million of Rain.		
	Calculated from daily Determinations (corrected).	Determined in Mixture at end of Month.	Re-analysis, Dec. 1882.
July	0·399	0·618	0·638
August	0·183	0·178	0·172
September	0·309	0·350	0·288
October	0·309	0·214	0·255
November	0·239	0·237	0·226
December	0·234	0·196	0·175
Numerical Mean.. ..	0·279	0·299	0·292

On looking at these figures it appears that the ammonia in the rain-water possesses considerable permanence; in one or two cases only is there any distinct diminution of ammonia by keeping, while in the case of the July water a considerable rise has taken place. Further re-analyses of old samples of rain-water, which we need not give in detail, show that a considerable diminution of ammonia by keeping is rare, and the increase of ammonia more common. In fifteen monthly mixtures of rain-water the mean alteration in composition during 1 to 1½ year was, in fact, from 0·457 to 0·478 of nitrogen as ammonia per million of water. The rise in ammonia, which is observed in some of these cases, is probably due to the decomposition of the nitrogenous organic matter contained in the rain. That the ammonia in rain should be apparently so little liable to nitrification will probably excite surprise; it must be recollected, however, that the rain-water in question contains a very distinct amount of lead in solution, derived from the gauge in which it is collected, and this is very probably fatal to the life of the nitrifying organism.

In Table III. the means calculated from the determinations in

TABLE III.—The AMOUNT of various MONTHLY RAINFALLS, and the AMOUNTS of NITROGEN as AMMONIA per MILLION of RAIN, and per ACRE, 1878–83.

MONTH.	1878.	1879.	1880.	1881.	1882.	1883.	Mean. June, 1881, to May, 1883.	Mean. 1878 to 1883.
				RAINFALL—INCHES.				
January	..	2·849	0·550	1·139	1·572	3·304	2·438	1·883
February	..	3·799	2·901	3·705	2·020	4·344	3·182	3·354
March ..	0·977	1·183	1·128	..	1·566	0·885	1·225	1·148
April ..	4·093	2·790	2·161	0·997	3·925	1·477	2·701	2·574
May ..	..	3·481	0·742	1·376	2·068	1·886	1·977	1·911
June ..	..	5·551	1·966	1·633	3·926	..	2·780	3·269
July ..	..	..	5·261	1·762	2·087	..	1·925	3·037
August ..	..	..	..	5·817	2·075	..	3·946	3·946
September	1·462	3·131	5·858	2·171	2·287	..	2·229	2·982
October ..	..	0·815	5·939	3·046	6·517	..	4·782	4·079
November	..	..	..	3·475	3·443	..	3·459	3·459
December	..	0·823	3·472	4·383	3·283	..	3·833	2·990
Total ..	..	..	..	..	34·798	..	34·477	34·632
				NITROGEN AS AMMONIA, PER MILLION OF RAIN.				
January	..	0·219	0·495	0·659	0·422	0·213	0·280	0·320
February	..	0·298	0·371	0·467	0·227	0·199	0·208	0·314
March ..	0·357	0·638	0·371	..	0·313	0·856	0·507	0·483
April ..	0·466	0·617	0·881	0·604	0·319	0·576	0·389	0·533
May ..	..	0·470	1·276	0·631	0·535	0·412	0·476	0·557
June ..	..	0·384	0·508	0·412	0·445	..	0·436	0·425
July ..	..	..	0·309	0·618	0·503	..	0·556	0·413
August ..	..	..	..	0·178	0·453	..	0·250	0·250
September	0·576	0·412	0·160	0·350	0·401	..	0·377	0·318
October	..	0·988	0·165	0·214	0·254	..	0·241	0·251
November	..	..	..	0·237	0·137	..	0·187	0·187
December	..	1·038	0.162	0·196	0·360	..	0·266	0·289
Average	..	..	..	..	0·343	..	0·316	0·340
				NITROGEN AS AMMONIA, IN LBS. PER ACRE.				
January	..	0·141	0·062	0·170	0·150	0·159	0·155	0·136
February	..	0·256	0·243	0·391	0·104	0·196	0·150	0·238
March ..	0·079	0·171	0·095	..	0·111	0·171	0·141	0·125
April ..	0·432	0·389	0·431	0·136	0·283	0·192	0·238	0·311
May ..	..	0·370	0·214	0·196	0·250	0·176	0·213	0·241
June ..	..	0·482	0·226	0·152	0·395	..	0·274	0·314
July ..	..	..	0·368	0·246	0·238	..	0·242	0·284
August ..	..	..	..	0·234	0·213	..	0·224	0·224
September	0·191	0·292	0·212	0·172	0·208	..	0·190	0·215
October	..	0·182	0·222	0·147	0·375	..	0·261	0·232
November	..	..	..	0·186	0·107	..	0·147	0·147
December	..	0·193	0·127	0·194	0·267	..	0·231	0·195
Total ..	..	..	..	..	2·701	..	2·466	2·662

increase in the quantity of

In Table IV. the whol
mixtures are grouped acco
and the results for the su
are given separately from
to March).

TABLE IV.—The AVERAGE
MONTHLY RAINFALLS of di
and the WHOLE YEAR.

Groups of Rainfall.	Summer Months.			
	Examples.	Mean Rainfall.	Nitrogen Ammoni	
			Per Million.	Lb p Ac
		In.		lb
Below 1 inch ..	2	0·87	·690	·1
1 to 2 inches.. ..	7	1·66	·527	·1
2 to 3 inches.. ..	7	2·23	·637	·2
3 to 4 inches.. ..	4	3·62	·410	·3
Above 4 inches ..	5	5·32	·287	·34
	25	2·80	·423	·26

The gradual decrease in
million of rain as the rain
is plainly shown by these
brought down per acre neve

yielded an average of 0·254 of nitrogen as ammonia per million of rain. Determinations in fresh monthly mixtures, extending over two years, have given an average of 0·316; and determinations in fifty monthly mixtures, rather more than half consisting of old collections, an average of 0·340 of nitrogen as ammonia per million of rain.

It is quite evident that the results now obtained, while they agree well with those given by Frankland's analyses, are much lower than those furnished by the earlier analyses made at Rothamsted, or by Professor Way. Can there be any error in the recent determinations tending to deficiency? Professor J. W. Mallet has lately called attention to the necessity of supplying the condenser with ice-cold water when distilling ammonia, if loss is to be avoided. Thus, when distilling 1 milligram of ammonia from 500 cubic centimeters of water in the ordinary way, he found a loss of 14·5 per cent., and when distilling 0·5 milligram, a loss of 7 per cent., the temperature of the distillates being 27° to 28° C. The temperature of our distillates may in summer time be as high as the point just named; there seem, however, no grounds for supposing that an appreciable loss of ammonia has occurred. In the first place, the quantity of ammonia in the retort has not exceeded 0·1 milligram, and has therefore been much below that mentioned by Professor Mallet. Further, in a determination made in June with a supply of iced water, the distillate having a temperature of 11° C., there was no appreciable difference in the amount of ammonia found from that obtained in a determination made in the ordinary way with a distillate at 25° C.

The evidence thus points to the conclusion that the early determinations of ammonia in rain erred on the side of excess. The method employed at Rothamsted in 1853–4 is given in detail in the Report of the British Association for 1854. The method used by Way in 1855–6 is described in the volume of this 'Journal' for 1856, p. 159. To enter upon a full discussion of these methods would lead us into chemical details unsuited to the present paper. It may be stated, however, that in both cases the ammonia was determined alkalimetrically, a method admittedly less delicate than the more modern Nessler process. Again, it has been stated by Schloesing, that by the use of a glass condenser the distillate may acquire alkali from the glass, and it is obvious that, so far as this may have happened, the effect would be to give high results by the alkalimetric method. There is also the further question whether a larger proportion of the nitrogenous organic matter was not converted into ammonia, and determined as such.

Assuming, then, the new determinations to be substantially correct, what estimate can be given of the amount of combined nitrogen annually furnished by the rain at Rothamsted?

If we take the results of the daily determinations during six months, June to December 1881, as representing half a year, then the nitrogen as ammonia supplied in the rain in the course of one year will amount to 2·374 lbs. per acre. If we take the results furnished by the analyses of fresh monthly mixtures during two years, the annual amount becomes 2·466 lbs. per acre. If the analyses of old monthly mixtures are included, the quantity of nitrogen as ammonia becomes 2·662 lbs. per acre per annum. The quantities shown by these three methods of estimation agree well together, but the first will probably most nearly represent the ready formed ammonia supplied by rain; we have learnt, indeed, that in the case of the Rothamsted rain-water, collected in a leaden gauge, the quantity of ammonia tends to increase with the age of the water, a part of the organic nitrogenous matter present in the rain doubtless undergoing decomposition, ammonia being produced.

The two series of determinations of nitric acid in Rothamsted rain, made by Way and by Frankland, have been described in the earlier Report. Way's results of two years' (1855–6) analyses of rain, gave a mean of 0·12 of nitrogen as nitric acid per million of water; equal to 0·75 lb. of nitrogen per acre for the years in question. Frankland, using a more modern method of analysis, found a nearly similar proportion of nitric acid in rain-water. The numerical mean of 34 determinations in rain, excluding dew, gave 0·14 of nitric nitrogen, while the average amount in 28 rainfalls of which the quantity was known, was 0·149 of nitric nitrogen per million of water. If we reckon the present average rainfall at Rothamsted (about 29 inches) on the latter estimate, the quantity of nitrogen as nitric acid annually supplied in the rain becomes nearly 1·0 lb. per acre. The total nitrogen as ammonia and nitric acid is thus about 3·3 lbs. per acre per annum.

We have yet to take account of the nitrogenous organic matter present in rain-water. The mean quantity of nitrogen in organic combination found by Frankland in 69 samples of Rothamsted rain was 0·19 per million of water, while the average amount in the mixed rainfall of 56 collections of known quantity was 0·165 per million. Taking the last-named estimate, and with an assumed rainfall of 29 inches, the quantity of nitrogen as organic matter annually contributed in the rain becomes 1·08 lb. per acre. In the case of Frankland's analyses, however,

the samples of rain-water were of some age, and a part of the organic nitrogen had doubtless become ammonia.

Bearing this fact in mind, we may probably take 4·5 lbs. per acre as the best estimate we can at present give of the total combined nitrogen annually supplied in the Rothamsted rainfall. This is only about two-thirds as much as the earlier results indicated as due to ammonia and nitric acid alone; but it is not improbable that, in their case, a larger proportion of the nitrogen of the nitrogenous organic matter was converted into ammonia, and estimated as such, than in the recent determinations.

In addition to the combined nitrogen carried down from the atmosphere in rain, we have to consider any gain to the soil or to the crop by direct absorption of ammonia or nitric acid from the air. As far as any gain from the atmosphere to the plant itself is concerned, there is very little direct experimental evidence on the point, but such as is available would lead to the conclusion that its amount is practically immaterial. As to the amount of gain by absorption by the soil, there is, unfortunately, no direct or satisfactory evidence at command. From such evidence as does exist, we are disposed to conclude that with some soils the amount will probably be greater, and with others less, than that supplied by the rainfall.

The Chlorine in Rain.

Determinations of chlorine in monthly mixtures of rain-water have been carried out at Rothamsted since June 1877; the results obtained up to the close of 1880 were published in the previous Report on Rain and Drainage. The determinations have been continued by means of the volumetric method before described, further experience with this method showing that it gave results almost identical with those obtained by the gravimetric method.

We need not discuss in detail the results obtained in individual months, which will be found in Table V. (p. 16), but turn at once to the columns showing the mean results of the six years' observations.

In the account given of the earlier results of this investigation it was pointed out that the winter rainfall was far richer in chlorine than the summer rainfall; we are now able to take a step further, and show the general character with respect to chlorine of each month in the year. The minimum amount of chlorine occurs in the rain of July. In August and September there is a distinct

TABLE V.—The MONTHLY RAINFALL, and the AMOUNTS of CHLORINE per MILLION of RAIN, and per ACRE, during SIX YEARS, 1877–83.

MONTH.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	Mean.
				RAINFALL—INCHES.				
January ..	..	1·750	2·849	0·550	1·139	1·572	3·304	1·861
February ..	..	1·804	3·799	2·901	3·705	2·020	4·344	3·096
March ..	..	0·977	1·183	1·128	2·153	1·566	0·885	1·315
April	..	4·093	2·790	2·161	0·997	3·925	1·477	2·574
May	..	4·976	3·481	0·742	1·376	2·068	1·886	2·422
June	1·435	2·505	5·551	1·966	1·633	3·926	..	2·836
July	3·284	0·656	4·244	5·261	1·762	2·087	..	2·882
August ..	2·596	4·976	6·558	1·069	5·817	2·075	..	3·849
September..	1·529	1·462	3·131	5·858	2·171	2·287	..	2·740
October ..	1·950	2·987	0·815	5·939	3·046	6·517	..	3·542
November..	5·159	4·545	0·814	2·919	3·475	3·443	..	3·393
December ..	2·279	1·601	0·823	3·472	4·383	3·283	..	2·640
Total ..	18·232	32·332	36·038	33·966	31·657	34·769	11·896	33·150
				CHLORINE PER MILLION OF RAIN.				
January ..	..	2·91	3·04	3·20	10·00	1·70	3·00	3·53
February ..	..	0·50	1·83	3·20	3·45	2·50	2·25	2·41
March ..	..	4·00	5·80	2·90	1·95	3·75	8·85	4·04
April	..	0·55	1·67	1·73	3·20	2·60	1·60	1·71
May	..	0·91	1·40	3·43	2·38	1·60	1·40	1·46
June	1·95	1·48	0·80	2·47	1·63	0·80	..	1·27
July	0·24	4·31	0·80	0·64	0·67	1·60	..	0·86
August ..	0·95	1·16	0·85	1·30	0·53	1·68	..	0·94
September..	1·73	2·28	1·05	0·97	0·75	1·15	..	1·17
October ..	3·40	2·58	2·65	3·00	4·20	2·28	..	2·91
November..	1·97	1·83	9·38	2·95	2·70	4·30	..	2·89
December ..	1·96	3·00	5·75	1·70	1·80	1·60	..	2·09
Average	1·64	1·64	1·75	2·01	2·32	2·15	2·73	1·99
				CHLORINE IN LBS. PER ACRE.				
January ..	..	1·15	1·96	0·40	2·58	0·60	2·24	1·49
February ..	..	0·20	1·57	2·10	2·89	1·14	2·21	1·69
March ..	..	0·88	1·55	0·74	0·95	1·33	1·77	1·20
April	..	0·51	1·05	0·85	0·72	2·31	0·53	1·00
May	..	1·03	1·10	0·58	0·74	0·75	0·60	0·80
June	0·63	0·84	1·01	1·10	0·60	0·71	..	0·82
July	0·18	0·64	0·77	0·76	0·27	0·76	..	0·56
August ..	0·56	1·31	1·26	0·31	0·70	0·79	..	0·82
September..	0·60	0·75	0·74	1·29	0·37	0·60	..	0·73
October ..	1·50	1·74	0·49	4·03	2·89	3·36	..	2·34
November..	2·29	1·88	1·73	1·95	2·12	3·35	..	2·22
December ..	1·01	1·09	1·07	1·34	1·79	1·19	..	1·25
Total ..	6·77	12·02	14·30	15·45	16·62	16·89	7·35	14·92

but not a very large increase in quantity. In October and November a great rise occurs, the quantity of chlorine contained in the rain being three times as large as during the two preceding months. After this period of maximum there is a fall, but the chlorine remains high throughout the winter months, the diminution towards the summer period not commencing till April. The rain of March has yielded the highest proportion of chlorine per million of water, but this is partly due to the small rainfall of the month. Rather more than two-thirds of the annual supply of chlorine is contributed by the winter months.

In the next Table the chlorine determinations in 72 monthly rainfalls are grouped according to the amount of the rainfall, and according to the season of the year.

TABLE VI.—The AVERAGE AMOUNT of CHLORINE in MONTHLY RAINFALLS of different QUANTITY, in SUMMER, WINTER, and the WHOLE YEAR.

Groups of Rainfall.	Summer Months.				Winter Months.				Whole Year.			
	Examples.	Mean Rainfall.	Chlorine.		Examples.	Mean Rainfall.	Chlorine.		Examples.	Mean Rainfall.	Chlorine.	
			Per Million.	Lbs. per Acre.			Per Million.	[illegible] per Acre.			Per Million.	Lbs. per Acre.
		In.		lbs.		In.		lbs.		In.		lbs.
Below 1 inch ..	3	0·80	3·58	0·65	6	0·81	5·76	1·06	9	0·81	5·04	0·92
1 to 2 inches	10	1·56	1·74	0·61	9	1·52	3·46	1·19	19	1·64	2·55	0·89
2 to 3 inches	9	2·30	1·40	0·73	7	2·59	2·65	1·55	16	2·43	1·98	1·09
3 to 4 inches	6	3·55	1·25	1·01	8	3·44	2·82	2·20	13	3·48	2·20	1·74
Above 4 inches ..	9	5·26	0·81	0·96	6	5·16	2·23	2·59	15	5·22	1·37	1·61
	36	2·88	1·21	0·79	36	2·64	2·84	1·70	72	2·76	1·99	1·24

The results do not fall into a very regular series. It would appear that in summer the supply of chlorides is very limited, for a large increase in the rainfall is attended with but little rise in the quantity of chlorine brought upon an acre. In winter, on the other hand, the supply of chlorides in the atmosphere is so constantly renewed, that an increased rainfall results in a considerable addition to the supply per acre. The rather wide irregularities in the composition of the groups of rainfall for the whole year, are principally due to the different proportion of summer and winter months which enters into the various groups.

The large excess of chlorides found in winter rain is probably due in great measure to the chlorides volatilised during the combustion of fuel; the excess in question is too uniform

partial study has been m
with no definite result.

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At the Rothamsted Laboratory no attempt has been made to determine the amount of sulphuric acid present in the rainfall of each month; the determinations have been made in mixed samples of water representing the rainfall of the six summer and of the six winter months. Approximate determinations of sulphuric acid in forty monthly mixtures of rain-water collected in the large gauge at Rothamsted have, however, been made by Dr. W. J. Russell, who is at present investigating the chemistry of rain.

The method of determination at Rothamsted has been to concentrate about 15 lbs. of rain in a glass retort, adding a little hydrochloric acid at the last; then filtering, precipitating the sulphuric acid with chloride of barium in the usual manner, and collecting and weighing the precipitate. Working in this manner, four mixed samples of rain-water, representing the fall during two summers and two winters, have given the following results. The sulphuric acid is reckoned as anhydride (SO_3).

TABLE VII.—The AMOUNT of SULPHURIC ACID in the RAINFALL of the SIX SUMMER and SIX WINTER MONTHS of TWO YEARS, 1881–3.

PERIOD OF COLLECTION.	Rainfall.	Sulphuric Acid.			
		Per Million of Rain.		In Lbs. per Acre.	
		Rain from Glass Funnel.	Rain from Large Gauge.	Rain from Glass Funnel.	Rain from Large Gauge.
	Inches.			lbs.	lbs.
April to September, 1881 ..	13·76	2·64	3·97	8·2	12·4
October to March, 1881–2 ..	15·86	2·29	3·66	8·2	13·1
April to September, 1882 ..	16·37	2·67	4·15	9·9	15·4
October to March, 1882–3 ..	21·78	2·15	3·99	10·6	19·7
Average per annum ..	33·89	2·41	3·95	18·5	30·3

It will be noticed at once that the rain-water furnished by the large gauge has yielded considerably more sulphuric acid than that collected in glass vessels only. There can be little doubt that the former results are in excess of the truth. Dr. Russell informs us that in his experience vulcanised caoutchouc is a constant source of sulphuric acid. We will confine our attention, therefore, to the results shown by the rain-water collected in the glass funnel.

The sulphuric acid (SO_3) contained in the rain-water collected in glass vessels has averaged in two years 2·41 per million of water, amounting to 18·5 lbs. per acre per annum. This quantity would appear to be about sufficient for the demands of

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SUMMARY C

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2. Analyses during two year

2·374 lbs.; from the analyses during two years of fresh monthly mixtures, 2·466 lbs.; from the analyses of fifty monthly mixtures, many of them old, 2·662 lbs. The nitrogen as nitric acid is apparently, from Frankland's and Way's results, about 1·0 lb. per acre, and the nitrogen as organic matter a similar quantity. The total combined nitrogen in the annual rainfall at Rothamsted would thus be about 4·5 lbs. per acre.

4. Six years' determinations of chlorine in monthly mixtures of rain give an average of 1·99 per million of water, or 14·92 lbs. per acre, equal to 24·59 lbs. of pure common salt. Two-thirds of the chlorides fall in the six winter months, October to March. The minimum quantity falls in July; the maximum in October and November.

5. Determinations of sulphuric acid in the rain of two years have given a mean of 2·41 per million (reckoned as anhydride), or 18·5 lbs. per acre per annum. The sulphuric acid occurs in nearly equal quantity in summer and winter.

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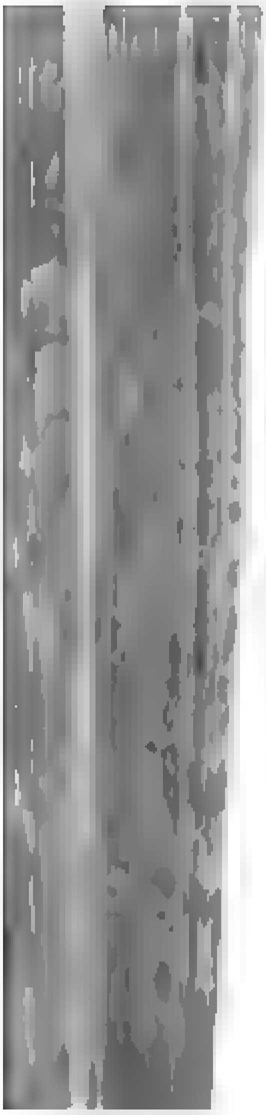

THE NITROGEN AS NITRIC ACID,

IN THE

SOILS AND SUBSOILS

OF SOME OF THE

FIELDS AT ROTHAMSTED.

BY

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AND
R. WARINGTON, F.C.S.

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VOL. XIX.-

NITROGEN AS NITRIC ACID,

IN THE

SOILS AND SUBSOILS OF SOME OF THE FIELDS AT ROTHAMSTED.

CONTENTS.

In the previous Report in this 'Journal,' "On the Amount and Composition of the Rain and Drainage-Waters collected at Rothamsted" (xvii. [2] 241, 311; xviii. 1), an account was given of the quantities of nitrates and chlorides found in the drainage-waters from the uncropped and unmanured soils forming the three soil drain-gauges at Rothamsted. An account was also given of the amount of nitrates, chlorides, and other constituents found in the drainage-waters from the variously manured plots in Broadbalk Wheat-field. Various important conclusions were drawn from these analyses of drainage-waters, and especially from the amount of nitrates present, which varied greatly according to the cropping and manuring of the land. We now propose to proceed a step further, and describe the results which have been obtained by actual determinations of nitrates in soils of various history.

The matter at our disposal embraces miscellaneous determinations of nitrates and chlorides in various soils on the Rothamsted Farm, both fallow and cropped; and also a series of determinations of nitrates and chlorides in the soils of the variously manured plots of the Experimental Wheat and Barley fields. The examination of these soils has, in the great majority of cases, been confined to the depth of 27 inches from

the surface. Of the amount of nitrates or chlorides which may be present in the lower depths of the subsoil, under various circumstances, we have as yet but little information. In the present paper attention will be confined to the amounts of nitrates found in the soils.

Method of Soil-sampling, and of Analysis.

The samples of soils have, with few exceptions, been taken in the manner first adopted at Rothamsted in 1856, and uniformly employed since, though not hitherto described in this 'Journal.' A rectangular tube, made of stout sheet iron, 6 inches square and generally 9 inches deep, having a strong rim outside its upper edge, is driven into the soil until the upper edge is level with the surface of the land. The contents of the tube are carefully removed without disturbing its position, and constitute the sample of the first 9 inches of soil. If a sample of the second 9 inches is to be taken, the empty iron tube is covered with a lid, and the soil surrounding it cleared away down to the level of its lower edge; the tube is then again driven into the soil, till its upper edge is at the level which its lower edge previously occupied; the contents of the tube are now a sample of the second 9 inches of the soil. By proceeding in this way samples may be taken to any desired depth. An iron tube 12 inches square is sometimes used for taking a sample of the surface soil when this is covered with vegetation.

By this method of sampling the soil and subsoil are obtained in their true proportion. The samples taken also represent a known area and depth of soil; the results of their analysis consequently admit of comparison with each other; the constituents found can also be reckoned into pounds per acre. It is much to be desired that the taking of soil-samples with the spade should be entirely discarded. Samples so obtained represent variable depths and no definite area, and they can only by accident include the true proportion of soil and subsoil; the results of their analysis are consequently of little value for purposes of comparison or calculation.

Both surface-soil and subsoil being more or less irregular, it is always necessary to take samples from several places on the same plot, or in the same field. The samples of the surface-soil are, as a rule, kept separate, a mixed sample being made of a part only, and the remainder reserved for reference or separate analysis. The samples of subsoil are generally at once mixed. Each sample is weighed in the field as soon as collected; it is then broken into small pieces, spread on trays, and dried in a stove-room at a temperature of about 55° C. (131° F.). The

soil when dried is further pulverised; all stones retained by a sieve with ¼-inch meshes are removed, and all visible roots; the remaining soil is then finely powdered, and stored in bottles for analysis. The stones, roots, and fine soil obtained from the original sample are all weighed.

The immediate partial drying of the soil is absolutely necessary, if it is desired to ascertain the quantity of nitrates present in the land from which the sample was taken, as the production of nitrates takes place with considerable rapidity in a moist soil freely exposed to air. The soil must not, however, be dried at too high a temperature, or loss of nitrates may occur.*

To ascertain the quantity of nitrates present in the soil, 200 to 400 grams of the finely-powdered soil are extracted with water on a vacuum filter. The nitric acid is determined in the watery extract by a modification of Schloesing's method, the details of which have been described elsewhere.†

History of the Soils Examined.

It will be convenient to bring together under one head the necessary descriptions of the various soils in which nitrates (and chlorine) have been determined. All the fields we have to mention form part of the Rothamsted Farm. The soil is in every case a more or less heavy loam, with flints; having a deep clay subsoil, resting on chalk. In one instance only was the chalk reached at the depth of 6 feet. Samples were in every case taken from several places in the field or plot, and the analyses made on mixtures of these samples.

Little Hoos Field.—Sampled September 26–29, 1877. This field is not part of the strictly experimental land. In 1877 the crop was barley, in half of which clover had been sown. The division of the field we are here concerned with had grown cereal crops for eleven years, the last nine crops being barley. During the last seven years the annual manuring consisted of superphosphate, with 2 or 2½ cwts. of nitrate of sodium. Samples of soil were taken in four places from each division of the field; the sampling was carried to the depth of 54 inches.

Agdell Field.—Sampled September 24–25, 1878, and September 8, 1882. In this field systematic experiments upon the ordinary four-course rotation have been conducted since 1848. We are only here concerned with two divisions of the field, representing respectively the highest and lowest condition

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* 'Trans. Chem. Soc.' 1882, p. 351. † Ibid. pp. 345, 351.

of the soil. In the first division the turnips are manured with 200 lbs. of ammonium-salts (equal parts sulphate and chloride), 2000 lbs. rape-cake, 3½ cwts. superphosphate (200 lbs. bone-ash and acid), 300 lbs. sulphate of potassium, 200 lbs. sulphate of sodium, and 100 lbs. sulphate of magnesium. The turnips are fed on the land, and the three following crops are unmanured. In the second division the turnips are manured with 3½ cwts. of superphosphate only, and are carted off the land; all the following crops are unmanured. In 1878 each division of the field was half in beans and half in fallow. Samples of soil were taken both from the bean land, and from that left as bare fallow through the summer; each plot was sampled in three places, but only to the depth of 18 inches.

In 1882 the soil bearing the fully-manured rotation was again sampled; it was then half in clover and half in fallow. The clover-land, and that under bare fallow, were each sampled in three places, to the depth of 27 inches.

Hoos Field.—1. *Wheat and Fallow.*—Sampled September 28, 1878, and March 29, 1881. The experiment with alternate wheat and fallow, both unmanured, has been in progress since 1851. Samples of soil were taken in September 1878, from three places, to the depth of 18 inches, both on the wheat and fallow land. In March 1881, the land which had grown wheat in 1880 was again sampled in five places, to the depth of 27 inches.

2. *Clover-land.*—Sampled March 29, 1881, and July 26–31, 1882. This portion of the field has been devoted to experiments with clover since 1849; but, owing to the repeated failure of the crop, the land has very frequently been in the condition of bare fallow; one crop of wheat and three of barley have also been taken. The five plots from which samples of soil were taken in 1881 had been manured either with superphosphate; or with the sulphates of potassium, calcium, and magnesium, with chloride of sodium; or with mixtures of these manures; but they had received no nitrogenous manure since the commencement of the experiment in 1849. In March 1881, single samples of soil were taken from each plot to the depth of 27 inches. The analyses were made on a mixture of the five samples.

In July 26–31, 1882, samples of soil were taken from two portions of two of the above five plots. The two portions with which we are at present concerned grew respectively Bokhara clover (*Melilotus leucantha*), and white clover (*Trifolium repens*). Both of the plots had been manured with the sulphates of potassium, calcium, and magnesium, and chloride of sodium, with superphosphate; no nitrogenous manure had been applied.

Samples of soil were taken from two places on each plot to the depth of 54 inches.

3. *Barley-land.*—Sampled February 24 to March 7, 1882. A large part of Hoos Field has been continuously cropped with barley since 1852. Particulars as to the manures applied, and the produce obtained on those plots with which we are at present concerned, will be found in Table I. The "mixed mineral manure" consists of superphosphate, with the sulphates of potassium, sodium, and magnesium. The ammonium-salts are a mixture of equal parts sulphate and chloride. The manures are all ploughed-in in the spring, before sowing the barley. The samples of soil were taken between February 24 and March 7, 1882, from four places on each plot, to the depth of 27 inches.

TABLE I.—MANURING and ANNUAL PRODUCE PER ACRE of certain Plots in HOOS BARLEY FIELD.

PLOT.	MANURING.	Average Produce, 30 years, 1852–81.		Produce, 1881.	
		Dressed Corn.	Total Produce (Corn and Straw).	Dressed Corn.	Total Produce (Corn and Straw).
		Bushels.	lbs.	Bushels.	lbs.
1 O.	Unmanured	17⅞	2150	17⅞	1609
2 O.	Superphosphate	23	2604	19¼	1822
3 O.	Sulphates of Potassium, Sodium, Magnesium	19⅞	2296	17⅛	1709
4 O.	Mixed Mineral Manure	24¼	2753	17⅞	1770
1 A.	200 lbs. Ammonium-salts	30¾	3612	33⅛	3249
2 A.	" Amm.-salts, and Superphosphate	44⅞	5368	43⅝	4195
3 A.	" " , and Sulp. Pot., Sod., Mag.	33½	4023	37⅜	3776
4 A.	" " , and Mixed Minerals ..	44½	5534	42⅝	4392
1 AA.	275 lbs. Nitrate of Sodium	34⅛	4147	34⅞	3762
2 AA.	" Nit. Sod., and Superphosphate ..	46⅞	5784	43¼	4141
3 AA.	" " , and Sulph Pot., Sod., Mag.	34⅞	4421	36⅝	4152
4 AA.	" " , and Mixed Minerals ..	47⅛	6007	47¼	5114
1 C.	1000 lbs. Rape-cake	43¾	5243	41⅛	4576
2 C.	" " , and Superphosphate ..	45	5515	48	5240
3 C.	" " , and Sulph. Pot., Sod., Mag.	41½	5168	40½	4417
4 C.	" " , and Mixed Minerals ..	45½	5661	45	4778
7¹	Unmanured (Farmyard-manure, 1852–71)	34¼*	4020*	29⅞	3063
7²	14 tons Farmyard-manure	49	6040	53¾	5707

* Average produce of 10 years (1872–81) without manure.

Clay Croft and Foster's Field.—Sampled October 3–4, 1881. These two fields are under the ordinary cultivation of the farm. The preceding cropping in each case had been—barley with guano in 1880, barley with superphosphate and nitrate of sodium in 1879, wheat with nitrate in 1878. Foster's Field had received dung in 1877; Clay Croft being at the same time fallow. Both fields were in bare fallow when sampled. Samples were taken in each case from three places, to a depth of 27 inches.

Broadbalk Field.—Sampled October 10–18, 1881. This field has been continuously cropped with wheat since 1843–4; the manuring and average produce of the plots with which we are concerned at present will be found in Table II. The "mixed mineral manure" and the "ammonium-salts" are similar to those applied to the barley in Hoos Field. The ammonium-

TABLE II.—MANURING and ANNUAL PRODUCE per ACRE of certain Plots in BROADBALK WHEAT-FIELD.

PLOT.	MANURING.	Average Produce, 1852–81.		Produce, 1881.	
		Dressed Corn.	Total Produce (Corn and Straw).	Dressed Corn.	Total Produce (Corn and Straw).
		Bushels.	lbs.	Bushels.	lbs.
2	14 tons Farmyard-manure	33¼	5696	30⅞	4274
3	Unmanured	13⅝	2106	13⅞	2009
4	Unmanured	14	2228	12⅝	1591
5 A	Mixed Mineral Manure	15⅛	2394	12⅞	1715
6 A	200 lbs. Ammonium-salts and Mixed Minerals	23⅛	3954	21⅛	2923
7 A	400 lbs. " " "	32¼	5710	27⅞	4007
8 A	600 lbs. " " "	36⅛	6778	32¼	5255
9 A	550 lbs. Nitrate of Sodium and Mixed Minerals	36⅝	6903	35¼	5911
9 B	550 lbs. Nitrate of Sodium, alone	23⅝	4293	22⅞	3241
10 A	400 lbs. Ammonium-salts, alone	20¼	3450	18⅞	2465
10 B	400 lbs. Ammonium-salts, alone	23¾	3923	19⅞	2658
11 A	400 lbs. Amm.-salts, and Superphosphate ..	26⅛	4387	22	3020
12 A	" " , Superphos. Sulp. Sodium	31¼	5326	25⅝	3409
13 A	" " , Superphos. Sulph. Potass.	31	5472	28⅞	4056
14 A	" " , Superphos. Sulph. Mag.	31⅝	5465	28⅝	4015
15 A	" " , Mixed Minerals [1] ..	30⅝	5289	25⅛	3452
16 A	Unmanured since 1865	[2] 14⅞	2356	13⅝	1720
17 A	Mixed Mineral Manure [3]	[4] 15⅛	2549	13⅞	1732
18 A	400 lbs. Ammonium-salts [3]	[5] 29¼	5145	31⅛	4437
19	1700 lbs. Rape-cake [6]	28¼	4758	24⅛	3353

[1] For 1872, and previously, 400 lbs. Sulphate of Ammonium, with Mixed Minerals.

[2] Average produce of 17 years, 1865–81, without Manure; previously manured with 800 lbs. Ammonium-salts and Mixed Minerals.

[3] The Manures on these two Plots alternate each year.

[4] Average produce of Mineral Manure, alternating with Ammonium-salts.

[5] Average produce of Ammonium-salts, alternating with Mineral Manures.

[6] For 1878, and previously, 300 lbs. Sulphate of Ammonium, 500 lbs. Rape-cake, with Superphosphate prepared with Hydrochloric Acid.

salts and nitrate of sodium are applied as a top-dressing in March. On Plot 15 the ammonium-salts have since 1878 been ploughed or harrowed-in in autumn. The farmyard-manure and rape-cake are also applied in autumn. During twelve seasons, 1868–79, the straw of the preceding crop was returned to the land in the form of chaff in the A division of Plots 5, 6, 7, 8, 11, 12, 13, 14, and on 17 or 18, according to which of the two received mineral manure only. On Plot 15A the straw was returned during six seasons, 1874–9. The effect of the straw on the produce has been very small. Further particulars of the manuring will be found in the previous Report. The samples of soil were taken between October 10 and 18 from six places on each plot, to the depth of 27 inches. In most cases in which a plot consists of two "lands," only the A division was sampled.

Geescroft Field.—Sampled April 9–13, 1883. This field has been cropped with beans since 1847, but in the later years the produce has much fallen off, and wet seasons have so interfered with the cultivation that the experiment has been discontinued. Since 1870, small crops of beans have been obtained in 1874, 1875, 1877, and 1878; and the usual manures have been applied in 1875, 1876, and 1878. In 1879, 1880, and 1881 the land was ploughed several times, but no seed sown. In 1882 the land was ploughed in February; grass-seeds were sown in September, which failed. In April 1883, samples of soil were taken from most of the plots, in two or four places, and in some instances to the depth of 72 inches.

The Nitrogen as Nitrates in Soils of various History.

In the previous Report the three drain-gauges at Rothamsted, containing uncropped and unmanured soil, were described, and the results of the systematic analysis of the drainage-waters during the last four years were given. We are now able to give the mean results of six years, May 1877 to April 1883. The nitrogen as nitrates has averaged, in the case of the soil 20 inches deep, 42·5 lbs.; in that of the soil 40 inches deep, 36·1 lbs.; and in that of the soil 60 inches deep, 41·9 lbs. per acre per annum. The mean of the three results is 40·2 lbs. This quantity will represent the mean annual production in the soils in question, if we assume that no loss of nitrates by reduction has taken place. The soils of the drain-gauges cannot, however, at present be taken as representing land in good agricultural condition. The soils have undergone no tillage during 13 years, saving the small disturbance resulting

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TABLE III.—The QUANTITY of NITROGEN as NITRATES found in FALLOW and CROPPED LAND variously manured.

No.	Previous Cropping and Manuring.	Nitrogen as Nitrates in Lbs. per Acre.			
		First Nine Inches.	Second Nine Inches.	Third Nine Inches.	Total.
	CLAY CROFT FIELD: sampled October 3, 1881.				
1	Fallow (ordinary cultivation)	16·4	26·5	15·9	58·8
	FOSTER'S FIELD: sampled October 3, 1881.				
2	Fallow (ordinary cultivation)	14·6	24·6	17·3	56·5
	AGDELL FIELD: sampled September 24–25, 1878.				
3	Fallow (Rotation fully manured)	30·0	18·8	not taken	48·8
4	Beans „ „ „	12·1	8·4	„	20·5
5	Fallow (Rotation, superphosphate only)	22·3	14·0	„	36·3
6	Beans „ „ „	7·2	3·3	„	10·6
	AGDELL FIELD: sampled September 8, 1882.				
7	Fallow (Rotation fully manured)	40·1	14·3	5·5	59·9
8	Clover „ „ „	11·4	4·8	3·4	19·6
	HOOS FIELD: sampled September 28, 1878.				
9	Fallow (unmanured land)	28·5	5·2	not taken	33·7
10	Wheat „ „	2·6	trace	„	2·6
	HOOS FIELD: sampled March 29, 1881.				
11	Wheat (unmanured land)	7·5	3·6	3·4	14·5
12	Clover (superphosphate and alkalies) ..	12·3	8·4	18·2	38·9

It is obvious that the quantity of nitrate found in a soil at the end of a summer's fallow does not represent the whole quantity of nitrate formed in the soil in the course of a year; a part of this has been already removed by drainage, and has passed into the subsoil. The experiments at Rothamsted afford some means of estimating this loss by drainage. The fallows we have just mentioned followed crops of barley. We may assume that in July, after the blooming of the barley, the soils to the depths in

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Nitrogen as nitrates in drainage, Augu	
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fallow is, however, greater tha

respectively 36·3 lbs. and 33·7 lbs. per acre, to the depth of 18 inches only. Both amounts are smaller than those found to the same depth in soils in good agricultural condition. The richness of the soil in nitrifiable matter has thus a great influence on the quantity of nitrate produced.

The fallow soils we have just mentioned were many of them very free from weeds, and none were very foul. In ordinary practice the land to be fallowed is often so foul that the nitric acid formed during the first summer and autumn will be taken up by the weeds as fast as it is produced. When, as is often the case, such land is not ploughed till the following spring, the loss of nitrates by drainage will be far smaller than on clean land.

Some further determinations of nitrates in uncropped soil will be found in Table IV. The previous history of Geescroft Field

TABLE IV.—The QUANTITY of NITROGEN as NITRATES, in LBS. PER ACRE, in CROPPED and UNCROPPED LAND, VARIOUSLY MANURED.

	Little Hoos. Sept. 1877.	Hoos Field, July 1882.		Geescroft Field, April 1883, uncropped land, previously Beans.			
	Barley. Nitrate and Superphos.	Bokhara Clover. Mineral Manure.	White Clover. Mineral Manure.	No Manure.	Formerly Mineral Manure.	Formerly Nitrate and Minerals.	Formerly Farmyard-Manure.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1st, 9 inches	15·7	3·4	8·6	4·2	3·5	3·3	13·6
2nd, 9 inches	1·1	1·0	3·0	5·4	6 7	6 0	8·7
3rd, 9 inches	1·1	0·6	1·9	4·7	5·1	4·2	7·3
4th, 9 inches	1·4	1·0	3·1	2·7	2·6	3·9	8·4
5th, 9 inches	1·2	0·8	4·4	3·2	1·7	1·9	4·4
6th, 9 inches	1·4	1·7	5·3	2·2	1·4	2·2	2·0
7th, 9 inches	not	not	not	3·0	1·1	1·5	1·7
8th, 9 inches	sampled	sampled	sampled	3·6	1·3	1·7	4·0
Above 27 ins.	17·9	5·0	13·5	14.3	15·3	13·5	29·6
Below 27 ins.	4·0	3·5	12·8	14·7	8·1	11·2	20·5
Total ..	21·9	8·5	26·3	29 0	23·4	24·7	50·1

has been already given (p. 9). The surface soil of the plot formerly manured with farmyard-manure is rich in nitrogen, and compares perfectly in this respect with the farmyard-manure plots in Broadbalk Wheat-field and Hoos Barley-field. The soils of the other plots are very low in nitrogen, and in a decidedly impoverished condition. During the summer of 1882, the land was without a crop. It was ploughed and harrowed in February, and then left untouched till September, when it was again harrowed and rolled, and grass-seeds sown, which failed. The samples of soil were taken on April 9–13, 1883.

Samples of soil taken at this time of the year, after the autumn and winter rains, seldom contain large quantities of nitrates near the surface. In the soils of Hoos Barley-field, sampled in March 1882 (Table VIII.), the nitrogen as nitrates amounted on the permanently unmanured plot to 15·7 lbs. in the first 27 inches; in the plots receiving only ash-constituents, to 18·3–23·5 lbs.; in the farmyard-manure plot to 44·1 lbs.; and in that which had received farmyard-manure for twenty years, but not for the last ten years, to 37·5 lbs. per acre. Compared with these quantities, the 14·3 lbs. found in the first 27 inches of the unmanured land in Geescroft, and the 29·6 lbs. in the plot formerly receiving farmyard-manure, are perhaps what we might expect, seeing that the drainage during the autumn and winter of 1882–3 was considerably greater than that of the previous year.* What, however, has become of the very considerable quantities of nitric acid which must have been produced in these soils during the last four years, in each of which the land was without a crop, and was frequently ploughed? How is it that larger quantities of nitrates are not found in the subsoil?

It is in the soil of the plot which was formerly heavily dressed with farmyard-manure that we should expect to find the largest accumulation of nitrate. This plot lies, however, near to the hedge green, and in taking the samples of soil, elm-roots were found down to the fifth nine inches from the surface: it is possible, therefore, that in this case the nitrates had been more or less removed from the subsoil. Omitting this plot from consideration, the facts furnished by the remaining plots still seem to point to a disappearance of nitrates in the subsoil. With the evidence at our command as to the production of nitrates in other exhausted soils at Rothamsted, we can hardly estimate the annual production of nitric acid in the soils in question as equal to less than 30 lbs. of nitrogen per acre. Taking even the excessive amounts of drainage shown during the last few years by the drain-gauges, the water percolating downwards from such a soil will contain an average of at least 7·5 parts of nitrogen as nitric acid per million of water. The field being pipe-drained at a depth of 3–4 feet, the quantity of water passing downwards will be diminished, but it is a question whether its average strength can be reduced thereby. Now the soil and subsoil of the unmanured plot in which nitrates were determined contained an average of 800,000 lbs. of water per acre in each nine inches of depth. We should

* The drainage shown by the 60-inch drain-gauge during seven months, August to February 1881–82, amounted to 12·515 inches; and in eight months, August to March 1882–83, to 17·814 inches.

expect, therefore, on the above suppositions, to find about 6·0 lbs. of nitrogen as nitrate in each depth of the soil, or 48 lbs. in all. A glance at the figures shows at once that a considerably smaller quantity is actually present in each of the three plots, and that the deficiency is most marked in the lower layers of the subsoil. It is a question, therefore, whether the nitrates produced in the surface soil have not suffered partial reduction in the lower layers of the clay subsoil; but the evidence on the point is confessedly very incomplete.

2. *Nitrates in Land growing Cereal Crops.*

In the previous Report it was shown that nitrates are always found in the drainage-waters of Broadbalk Wheat-field during the winter months. It was also shown that a large proportion of the ammonium-salts applied as manure is speedily nitrified after their application to the land. A good example of the latter fact is afforded by the analyses of the drainage-waters of Plot 15 (see Table V., p. 18), to which 400 lbs. of ammonium-salts per acre were applied on October 27.

It was further stated in the previous Report, that as the development of the wheat-crop proceeds, the assimilation of nitrates by the growing plant becomes so active, that in summer nitrates are not found in the drainage-waters of many of the plots in the Experimental Wheat-field. The plots which exhibit for a time a drainage free from nitrates are those which receive no nitrogenous manure, or which receive 200–400 lbs. of ammonium-salts with all the ash-constituents required by the crop. In a season very favourable to early growth, as 1882, the nitrates may disappear from the drainage-waters of the unmanured plots by the end of April; while in a very unfavourable season, as 1879, the disappearance may not occur till the beginning of June. The nitrates disappear from the drainage of Plot 6, receiving 200 lbs. of ammonium-salts with ash-constituents, soon after their disappearance from the drainage of the unmanured plots. On Plots 7 and 13, with 400 lbs. of ammonium-salts and the necessary ash-constituents, the disappearance of the nitrates from the drainage-waters is later, and small quantities may continue to be found for some time.

The quantity of nitrates which disappears from the soil in early summer is in some cases truly astonishing. In the case of the plots receiving a spring-dressing of ammonium-salts it may apparently amount to more than the quantity of nitrogen found in the crop at harvest. It must be recollected, however, that the crop as harvested does not represent the whole plant—the roots, stubble, some of the lower leaves, and shed

corn, being left behind in the soil. We must also take into account the presence of weeds, which doubtless actively assimilate the nitrates of the soil. It is possible, however, that when ammonium-salts are applied as a top-dressing in spring the whole of the ammonia does not rapidly change into nitrates, either from actual loss as ammonia, or from the presence of conditions unfavourable to rapid nitrification. It will be recollected that the calculations given in the previous Report (Table LI.) showed a considerable annual deficiency of nitrogen where 400 lbs. of ammonium-salts were applied in the spring, but none on Plot 15, where the salts were ploughed-in in the autumn.

To return from this necessary digression. The facts stated above point to the conclusion that in the case of land growing cereal crops, no nitrates, or very small quantities only, will be found in the first 27 inches of soil by the end of June, excepting in those cases where the quantity of nitrates in the soil has been greater than the crop has had power to appropriate.

The assimilation of nitrogen by a cereal crop practically ceases when blossoming is completed; from this point onward, therefore, nitrates may begin again to accumulate in the soil. If sufficient rain falls to keep the surface moist, we may expect nitrates to appear in the soil towards the end of July, or in August, and the soil at harvest may contain nitrates which a month previously had no existence. After harvest, if sufficient rain occurs, and especially if the land is ploughed, nitrification will actively continue. We may suppose that generally the maximum contents of nitrates will be reached about the end of September, and that from this time the quantity in the upper layers of the soil will in most cases tend to diminish, production being checked by the fall in temperature, while the removal of nitrates by drainage will in most seasons then become active.

The foregoing sketch of the course of change of the nitrates in a soil cropped with wheat or barley is founded mainly on the evidence furnished by the analyses of the drainage-waters. We have now to consider the evidence afforded by the analysis of the soils.

In Table III. (No. 10) will be found a determination of nitrates in the soil of a poor wheat-stubble in Hoos Field. The wheat had been grown, in alternation with fallow, for many years without manure. The crop was cut on Aug. 13, 1878; it yielded 19¾ bushels of dressed corn. The soil was sampled on Sept. 28. The first 18 inches of soil contained only 2·6 lbs. of nitrogen as nitrates. We have in the same Table (No. 11) a second determination of nitrates in the same soil, made in March 1881. The wheat-stubble of the previous year had been left unploughed up to the time of sampling. The nitrogen as

nitrates was now 11·1 lbs. per acre in the first 18 inches, and 14·5 lbs. in the first 27 inches of soil.

In Table IV. we have a determination of nitrates in a barley-stubble in Little Hoos Field. The land had grown 9 crops of barley in succession with artificial manures alone, chiefly nitrate of sodium and superphosphate. The crop was cut on Aug. 14–21, 1877; it amounted to 48 bushels. The samples of soil were taken Sept. 26–29. The land had not been ploughed at the time of sampling. The nitrogen in the form of nitrates is here 15·7 lbs. per acre in the first 9 inches. It seems improbable that this nitrate was a residue of the 2½ cwts. of nitrate of sodium (44 lbs. of nitrogen) applied as manure; the greater part of it had more probably been produced in the soil since Midsummer, especially as the rainfall in July and August was considerable. On a duplicate plot in the same field, in which clover had been sown with the barley, only 6·1 lbs. of nitrogen as nitrates were found in the first 9 inches of soil. The young clover had thus evidently continued to take up nitrates from the soil after the growth of the barley had ceased. The chief interest of the experiment centres, however, in the analyses of the subsoil, which in this case was sampled to an unusual depth. The insignificant amount of nitrate found—only 6·3 lbs. of nitrogen per acre in 45 inches of subsoil—presents a vivid picture of the exhaustion of soil-nitrates which may take place during the growth of a vigorous cereal crop.

We turn now to Broadbalk Wheat-field. A plan of this field, showing the position of the plots, and the system of drain-pipes, has been given in the previous Report. Samples of soil were taken from many of the plots in October 1865, and in some of these nitric acid was determined in the following year by Dr. Pugh's method. The quantity of nitric acid found was large; but as the soils had been stored in a moist condition, nitrification had probably taken place after the collection.

The plots of Broadbalk Field were again sampled in October 1881. The manuring of the field, the average produce of each plot, and the produce of the particular harvest (1881), after which the soil was sampled, have been already given in Table II. From the end of March to the end of July the weather had been decidedly dry. The wheat was cut on Aug. 8–11. Immediately after followed a deluge of rain, amounting in the whole month to 5·817 inches. The crop was not carted till Aug. 29–Sept. 1, and was greatly damaged. In September the rainfall was 2·171 inches. The land was scarified in the beginning of the month, and ploughed towards the end of it. The samples of soil were taken between October 10 and 18, the sampling being interrupted by heavy rain on the 14th. The

land was again ploughed and harrowed on October 27–29, and wheat drilled on all the plots.

Before calling attention to the quantity of nitrates found in the soils of the different plots at the time of sampling, it will be well to consider the evidence afforded by the composition of the drainage-waters collected during the same season. The drains in Broadbalk Field are from 2 feet to 2 feet 6 inches below the level of the land; whilst the nitrates have been determined in the soil to approximately the same depth, namely, 27 inches. The composition of the drainage-waters will be found in Table V. The thick black line shows the interval, October 10–18, in which the samples of soil were taken.

TABLE V.—The NITROGEN as NITRATES, in the DRAINAGE-WATERS of the PLOTS in BROADBALK WHEAT-FIELD, from March 1881 to January 1882.

PLOT.	March 5, 6, 7, Mixed.	August 30. A.M. 6·30.	August 30. P.M. 2–3.	Sept. 26.	Oct. 14.	Oct. 28.	Nov. 25.	Nov. 27.	Dec. 7.	Dec. 17, 19, 20, 22, Mixed.	Jan.
	Nitrogen as Nitrates per Million of Drainage-Water.										
2	5·1	..	..	..	..	..	18·9*	7·1	..	5·8	..
3 & 4	3·4	1·2	0·9	4·7	6·3	8·7	5·4	7·0	5·1	4·1	3·5
5	3·6	1·5	1·4	6·0	8·1	9·5	6 0	7·3	6·3	5·0	3·9
6	3·9	..	1·9	7·0	12·[illegible]	13·3	8·5	8·8	7.8	6·2	6·2
7	3·9	..	4·1	..	..	18·5	9·8	11·7	10·9	7·8	7·3
8	5·3	..	..	..	..	23·0	17·1	18·2	16·8	11 2	10·2
9	5·2	..	..	..	..	21·8	12·3	..	13·8	9 4	10·0
10	5 9	20·3	16·1	20·6	21·0	16·2	11·2	14·5	14·0	9·3	9·1
11	5 4	9·0	6·8	10·7	12 6	19·6	12·6	14·9	13·7	9·4	9·4
12	4 8	..	2·3	7·2	9·3	15·2	10·5	11.0	10·2	7·6	7·4
13	4 5	..	2·4	..	9·0	14·5	9·8	11·1	9·3	[illegible]	6·5
14	5 1	..	..	..	..	15·0	9·7	12·1	9·4	6·8	6·7
15	11·6	..	..	..	..	13·1	06·6†	40·5	34·8	26·4	22·4
16	3·1	..	0·3	..	7·4	8·6	5·1	6·3	4·1	3·4	2·9
17	3·9	1·0	0·4	8·8	9·6	10·7	5·4	6·8	5·6	4·1	3·7
18	3·9	..	..	..	..	11·6	7·5	9·0	7·1	5·6	4·0
19	12·1	..	..	..	..	14·9	19·6‡	19·2	10·0	15·6	..

* Farmyard-manure applied Oct. 27. † Ammonium-salts applied Oct. 27.
‡ Rape-cake applied Oct. 28.

The last running of the drains preceding the harvest of 1881 occurred on March 7. The top-dressings of ammonium-salts, and of nitrate of sodium (see Table II.), were applied to their respective plots on March 12. No running of the drain-pipes occurred till after harvest, on Aug. 30.

The drain-pipes of Plots 3&4, 5, 16, and 17, receiving no nitrogenous manure, all ran on Aug. 30; the water contained a

very small amount of nitric acid, amounting in the mean to barely 1·0 of nitrogen per million. The water from Plot 6, manured in the spring with 200 lbs. of ammonium-salts per acre, contained at the same time 1·9 of nitrogen per million. The waters from Plots 12, 13, and 7, receiving 400 lbs. of ammonium-salts, contained respectively 2·3, 2·4, and 4·1 of nitrogen per million.

With the evidence already before us, it scarcely admits of doubt that nitrates must have practically disappeared from the upper layers of the soil of the unmanured plots during the preceding summer; also from the soil of Plot 6; and probably, though less certainly, from Plots 13 and 7. The small amounts of nitrate appearing in the drainage-waters from these plots on Aug. 30, are therefore in all probability due to nitrification recommencing in the soils as they became saturated by the heavy rains of August. Nor is the fact that the waters from Plots 6, 12, 13, and 7, contain more nitrate than those of the unmanured plots, conclusive evidence that there was a residue of nitrate present through the summer in these cases; for wherever nitrogenous manure is applied, and larger crops are annually produced, there the soil is richer in nitrogenous organic matter (the residues of previous crops), and in consequence yields a larger quantity of nitric acid when nitrification sets in. That the nitrates in the waters of the plots already named were not derived from the washing out of a residue of nitrates, but from fresh nitrification, is further shown by the fact that the proportion of nitric acid rapidly increases with each running of the drains, till a maximum is reached on Oct. 23.

When we turn to the drainage of Plot 10, which had received 400 lbs. of ammonium-salts, like Plots 7, 11, 12, 13, 14, 15, and 18, but without any of the ash-constituents required for the crop, a very different state of things is manifest. Here the crop has been unable to assimilate all the nitrates at its disposal, and a considerable residue has remained in the soil throughout the summer. The first drainage-water from this plot is thus rich in nitrates, containing 20·3 of nitrogen per million, and the proportion is found to have decreased rather than increased by October 23.

The soils of Plot 9—on which nitrate of sodium, half with and half without ash-constituents, is applied; Plot 8—where as much as 600 lbs. of ammonium-salts with ash-constituents are applied; and, to a less extent, Plot 11—where potash is omitted in the manure—are in a condition more or less similar to Plot 10. In all these cases there is a considerable residue of nitrate remaining unassimilated by the crop, which appears in the drainage-water on the first running of the drains.

We now turn to the determinations of nitric acid in the soils of the various plots in Broadbalk Field. We must, however, at starting beg the reader to remember the considerable difficulty of the task we have attempted. The mean composition of the soil of a plot 352 yards long has to be calculated from samples taken from six holes equally distributed in its length; that the mixture prepared from such samples should sometimes fail to represent accurately the average composition of the soil is surely to be expected. In two instances in Broadbalk Field, and one in Hoos Field, the surface soil from individual holes has contained so high a proportion of nitric acid and chlorine, as to lead to the supposition that the sample had been taken from a spot contaminated by the droppings of horses when ploughing; or where possibly a bag of manure had been set down and emptied during sowing. In these cases the results given have been obtained from a mixture of five holes, or, in the case of Hoos Field, of three holes only. There is also always some difficulty in preserving a large number of soil-samples, in this case 160, entirely free from accidental contamination before they are put into bottles; and in one instance, that of the third depth of the unmanured Plot 16, it has been necessary to exclude the results of the analysis from the table, the nitric acid found being far larger than seemed possibly consistent with the truth. A small amount of error will, indeed, distinctly affect the result; the addition of one grain of nitric nitrogen to 1144 lbs. of soil would, in fact, make a difference of 1 lb. per acre in the quantity calculated for a depth of 27 inches. It is clear, therefore, that it will be unsafe to found conclusions on small differences between different plots; we must rather aim to seize the main features of the results.

In calculating the results of the analyses into pounds per acre, it has been assumed that the weight of soil per acre in the first 9 inches is 2,552,203 lbs.; in the second 9 inches, 2,706,573 lbs.; and in the third 9 inches, 2,750,601 lbs., these weights being the mean of all the samples taken on the present occasion, excluding only the surface soil of Plot 2. The analysis of this soil (receiving farmyard-manure) is reckoned on 2,456,509 lbs., the weight calculated from its own samples.

It is of interest to note, that even among the artificially manured plots there is an obvious tendency to give lower weights of surface soil the heavier the crops, that is, the greater the root development, and the amount of crop-residue. Hence the calculation of the analyses relating to the soils of such plots on the rather higher average weights, will so far give results somewhat in excess; whilst those relating to the poorer plots will be proportionally low.

In Table VI. will be found the quantities of nitrogen as nitric acid existing in the first, second, and third 9 inches of soil in the various plots of Broadbalk Field, when sampled on October 10–18, 1881. In the same Table are given the estimated quantities of nitrogen as nitrates removed from each plot in the drainage-water after the first starting of the drain-pipes on August 30. The estimates are calculated from the composition

TABLE VI.—NITROGEN as NITRATES in the SOIL and SUBSOIL, and in the DRAINAGE-WATER, of various PLOTS in BROADBALK WHEAT-FIELD, in lbs. per ACRE.

PLOT.	In the Soil when Sampled October 10–18, 1881.						Estimated as removed in Drainage, August 30—January 31.			Estimated in Soil if no Drainage before Sampling.
	First Nine Inches.	Second Nine Inches.	Third Nine Inches.	Total Twenty-seven Inches.	Excess over:— Plots 3 & 4	Excess over:— Plot 5A.	Before Soil Sampling.	After Soil Sampling.	Total	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
2	30·0	15·4	6·8	52·2	35·8	27·9	..	..	..	..
3	9·7	5·3	2·8	17·8	..	− 6·5	1·3	10·3	11·6	17·7
4	9·2	4·0	1·8	15·0	..	− 9·3				
5 A	12·6	7·1	4·6	24·3	7·9	..	1·3	11·9	13·2	25·6
6 A	16·5	7·5	4·7	28·7	12·3	4·4	1·5	16·0	17·5	30·2
7 A	22·8	11·3	5·7	39·8	23·4	15·5	[3·5]	20·6	24·1	43·3
8 A	21·1	13·9	7·8	42 8	26·4	18·5	?	30·1	..	..
9 A	19·7	10·0	8·2	37·9	21·5	13·6	?	25·2	..	..
9 B	16·3	20·1	17·7	54·1	37·7	29·8				
10 A	14·2	11·9	7·3	33·4	17·0	9·1	7·0	24·1	31·1	37·9
10 B	13·4	9·0	5·9	28·3	11·9	4·0				
11 A	17·9	9·3	3·6	30·8	14·4	6·5	4·7	22·8	27·5	35·5
12 A	15·3	10·3	4·4	30·0	13·6	5·7	2·7	18·1	20·8	32·7
13 A	13·1	8·9	2·6	24·6	8·2	0·3	2·7	16·7	19·4	27·3
14 A	16·1	8·7	3·6	28·4	12·0	4·1	?	17·1	..	..
15 A	13·4	10·7	4·1	28·2	11·8	3·9	..	..	..	..
16 A	10·6	5·0	[2·3]	17·9	1·5	− 6·4	1·7	8·7	10·4	19·6
17 A*	10·3	7·5	3·4	21·2	4·8	− 3·1	2·6	10·3	12·9	23·8
18 A*	11·4	8·4	5·2	25·0	8·6	0·7	?	13·2	..	..
19	14·1	13·0	7·1	34·2	17·8	9·9	..	..	..	..

* The manures on Plots 17 and 18 alternate. This year Plot 17 had received only Mixed Mineral Manure, and Plot 18, 400 lbs. of Ammonium-salts.

of the water issuing from the drain-pipes (Table V.), the quantity of the drainage being assumed as equal to that shown by the 60-inch soil drain-gauge. The amount removed in drainage *before* the samples of soil were taken is given separately in Table VI.; and in the right-hand column this amount is added to that found in the soil, thus showing, as far as in our power, the amount of nitrogen as nitric acid which would have been present in the soil if no drainage had occurred. In the case of several of the plots no drainage before soil-sampling

is recorded, the pipes, in fact, did not run. In all these cases loss of nitrates by drainage and diffusion doubtless took place, though we have no means of estimating the quantity actually passing below the first 27 inches of soil. Evidence that the amount passing into the subsoil by drainage and diffusion may in some cases considerably exceed that estimated from the composition of the pipe-drainage, is afforded by results obtained relating to the amount of the chlorides present in the soil.

As a very considerable amount of drainage took place in Broadbalk Field after the samples of soil were taken, it is obviously of interest to compare the results of the analyses of the soils with those of the subsequent drainage-waters. If the drainage-waters fairly represent the condition of the first 27 inches of soil on the different plots, the quantities of nitrate found in the waters should show a similar relation between themselves, as exists between the nitrates found in the soils of the corresponding plots. This comparison of the results of the soil-analysis with the composition of the subsequent drainage from the same plot, indeed brings to view some facts which would otherwise escape attention.

Turning now to the details of the soil-analyses, we observe, first, that the nitrates are most abundant in the first 9 inches of depth; the mean proportion at the three depths (excluding Plot 9B) is, in fact, as 100, 59, and 31. The nitrates have, in fact, mainly been produced near the surface, in most cases quite recently, and are now gradually passing downwards. The case is quite different, however, on Plot 9B, where more nitrate of sodium has been applied than the crop could make use of; here the nitrates are present in largest quantity in the second and third depths, and a part has probably passed to a still lower level. A large portion of this nitrate has existed in the soil ever since the application of the manure in March, and has since then, and especially since the removal of the crop, been moving slowly downwards by diffusion and drainage. From a similar cause, the quantity of nitrate in the lowest depth of Plots 8A, 9A, and 10A is also above the average.

Passing next to the quantity of nitrate found in the various plots, we observe that the unmanured soils of Plots 3, 4, and 16A, yield the lowest amounts, namely 17·8 lbs., 15·0 lbs., and 17·9 lbs. of nitrogen as nitrates per acre. Plot 5A, continuously manured with ash-constituents, yields 24·3 lbs.; this amount, however, bears a higher relation to that contained in the subsequent drainage than is shown by the adjoining Plots 3, 4, 6A, and 7A. Plot 17A, also receiving ash-constituents alone during the year in question, yields 21·2 lbs. per acre. Of the effect of the various ash-constituents in [illegible]

in the soil, or on the migration of soluble matters, we have at present no certain information.

When we turn to Plots 6A, 7A, and 8A, receiving respectively 200 lbs., 400 lbs., and 600 lbs. of ammonium-salts, with all the necessary ash-constituents, we find 28·7 lbs., 39·8 lbs., and 42·8 lbs. of nitrogen as nitrates per acre, the quantities increasing with each addition to the manure. The quantity of nitrate in the soil of Plot 8A bears a low relation to that found in Plots 6A and 7A. In the case of Plot 8A we are unable to form an estimate of the quantity of nitrate lost by drainage before the sampling of the soil, as the drain-pipe did not run till afterwards; the quantity lost by drainage and diffusion may well, however, have been greater than on Plot 7. The nitrate in the soil of Plot 8A is also very low in relation to that found in the subsequent drainage from the plot. If the proportion between the nitrate in the soil and that removed in the subsequent drainage were the same as on Plots 6A, 7A, and 9AB, the soil of Plot 8A would contain about 56 lbs. of nitrogen as nitrates. It seems possible that in this case an unusually large amount of nitrogen may have nitrified on the plot after the samples of soil were taken; nitrates might thus appear in the drainage which did not exist in the soil at the date of sampling.

In the soil of Plot 9A, where nitrate of sodium equivalent to 400 lbs. of ammonium-salts is applied, with ash-constituents, the nitrogen as nitric acid is 37·9 lbs., a quantity very similar to that found in Plot 7A, receiving the corresponding amount of ammonium-salts, and the same ash-constituents. On Plot 9B, where the same quantity of nitrate of sodium is applied, but without ash-constituents, the nitrogen existing as nitrates rises to 54·1 lbs., a large residue of nitrate unused by the crop clearly remaining in the first 27 inches of soil.

On Plots 10A and 10B, receiving 400 lbs. of ammonium-salts, without ash-constituents, there is deficient produce, and there will be a proportionally large amount of nitrate annually derived from the manure unused by the crop. The quantities found in the soil to the depth of 27 inches are nevertheless not relatively large—namely 33·4 lbs. and 28·3 lbs. of nitrogen as nitrates. The smaller amount is found in the soil of Plot 10B, where, owing to a residue of long previously applied ash-constituents, the crop is always rather better, and would therefore leave rather more crop-residue. In these facts there would seem to be evidence that the whole of the soil-nitrates found was not due to crop-residue, but partly to manure-residue also. That the amount remaining within the range of the soil-sampling was not larger on either plot, is consistent with the fact that there is a greater loss by drainage from these than from any of the other

plots receiving the same amount of ammonium-salts, as shown by the estimates for two years, as given in our former Report, and by the composition of the drainage previous to the soil-sampling, as given in Table VI. of the present Report; and it is to be supposed that more has also passed below the drain-pipes, and the range of the soil-samples.

Plots 11, 12, 13, 14, and 7, all receive 400 lbs. of ammonium-salts, and all the same amount of superphosphate, with the addition of sodium-salt to Plot 12, potassium-salt to Plot 13, magnesium-salt to Plot 14, and sodium- potassium- and magnesium-salt to Plot 7. Thus the conditions of the several plots as to soluble matters within the soil are very different. On Plot 11, with superphosphate, there is more produce than on Plot 10 without it, and therefore more crop-residue; but still there will be an excess of nitrates directly derived from the ammonium-salts, compared with the amount on either Plots 12, 13, 14, or 7, where there is considerably more growth. The quantity of nitrogen as nitrate found in the soil of Plot 11 to the depth of 27 inches is, however, only 30·8 lbs., or about the same amount as on Plots 10, 12, and 14. But both the previous and the recent records show a greater loss in the collected drainage of Plot 11 than of the other plots of the series under consideration, and there will doubtless be on the average more loss below the level of the drains, and of the range of the soil-sampling. Plots 7 and 13, both receiving potash, yield the heaviest crops of the series. If therefore the nitrates found to the depth of 27 inches depended wholly upon the amount of crop-residue, we should expect to find the largest amount in the soil of both these plots. The fact is, however, that the smallest amount within this series (24·6 lbs.) is found in the soil of Plot 13, with potassium, but without sodium- and magnesium-salts, and the largest amount (39·8 lbs.) in that of Plot 7, with sodium and magnesium, as well as potassium-salt applied. Even assuming there may be some error in the actual figures (and by comparison it would be judged that those for Plot 13 may be too low), the direction of the difference is in accordance with the estimates of average loss by pipe-drainage, Plot 13 showing more loss than Plot 7; whilst on the other hand, with the much higher amount of nitrates found in the soil of Plot 7 at the time of sampling, its immediately succeeding drainage is stronger. The conclusion is, that there is upon the whole a greater tendency to passage downwards by drainage, and less to retention within the first 27 inches of soil on Plot 13 than on Plot 7. Whether this be due to more free movement downwards, with the different conditions within the soil dependent on the different supply of saline matters, we have not the [illegible]

of deciding. Plot 7 should, it is true, have a somewhat greater accumulation of crop-residue, and should therefore yield rather more nitrates from that source. But only a small proportion of the excess of nitrogen as nitrates, which the figures as they stand show in the soil of Plot 7 to the depth of 27 inches, could be so accounted for. It is very probable, indeed, that a portion of the excess of nitrates found in the soil of Plot 7 is due to less free passage downwards, from whatever cause.

In addition to the various conditions above alluded to affecting the amount of nitrates produced, and their tendency to remain at higher, or to pass to lower levels in the soil, the very different condition as to moisture of the different plots after harvest must not be overlooked. Thus, it is estimated that more water, equal in amount to some inches of rain, has been evaporated from the soils yielding the heavier than from those yielding the lighter crops. This implies, of course, that much less subsequent rain will be required to bring the soil to an equal degree of saturation, and so far as it is dependent on this, to cause an equal passage downwards, in the case of soils giving the poorer than of those giving the heavier crops. Then there is also the possibility of a different mechanical condition of the soils of different plots.

On Plot 19, manured during the three preceding seasons with rape-cake alone, we find 34·2 lbs. of nitrogen as nitrates, a quantity considerably larger than that contained in the adjoining plots manured with ammonium-salts. As the rape-cake only slowly decomposes in the soil, a part of the nitrates found will in this case be due to the nitrification of a residue of the manure. A still more striking example of the production of nitrates from organic manures is afforded by Plot 2, which receives annually fourteen tons of farmyard-manure: here the quantity of nitrate in the soil amounts to 52·4 lbs. of nitrogen per acre, exceeding, in fact, every plot excepting that manured with an excess of nitrate of sodium.

The origin of the very considerable quantities of nitrates found in the soils of Broadbalk Field will require but little explanation after what has been already stated. The nitrates found in these soils in October have been produced by the nitrification of the original nitrogenous humic matters of the soil; or from the decay of crop-residues (roots, leaves, and stubble); or from the nitrification of organic nitrogenous manures, as rape-cake or farmyard-manure; or, possibly from the oxidation of residues of ammoniacal manure not previously nitrified; or they consist in part of residues of nitrates which have remained in the soil through the summer. Of the quantity of nitrates produced solely from the oxidation of nitrogenous humic matters, including crop-residue, we have examples in the

case of Plots 3 & 4, 16A, 5A, 17A, and probably of several others. Whether any of the nitrate on such plots as 7A and 9A, was due to a residue of nitrate left unused by the crop, must remain doubtful, but the amount of such residues can hardly be very large. Plot 9B affords a capital example of a large residue of nitrate left unappropriated by the crop. In Plots 2 and 19 we have examples of the influence of farmyard-manure and rape-cake in increasing the amount of nitrates produced in the soil. The amount of nitrification observed was probably in all cases considerably above the average, being largely due to the early saturation of the soil by the heavy rains of August.

As the nitrogenous organic matter in the soil was clearly the principal source of the nitric acid it contained, and as this nitrogenous organic matter is largely derived from the residues of previous vegetation, it will be of interest to compare the amount of nitric acid found in certain typical plots with the amount of nitrogen found by analysis in the first 9 inches of soil, and with the average amount of produce which the soil of each plot has yielded. This comparison will be found in Table VII. The nitrogen contained in the surface soil of each

TABLE VII.—NITROGEN AS NITRATES IN BROADBALK SOIL, October 1881, for 1000 of SOIL NITROGEN, and of AVERAGE PRODUCE.

Plot.	Manuring.	Nitrogen as Nitrates in Soil.		
		For 1000 of Soil Nitrogen.	For 1000 Average Produce.	
			Average 30 Years 1852–81.	Average 2 Years 1880–1.
3 & 4	Unmanured	6·7	7·6	8·6
6 A	200 lbs. Ammonium-salts, Mineral Manure	10·2	7·3	7·3
7 A	400 lbs. " " " " ..	12·9	7·0	7·8
8 A	600 lbs. " " " " ..	13·3	6·3	6·7
9 A	550 lbs. Nitrate of Sodium, Mineral Manure	12·4	5·5	6·1
9 B	550 lbs. Nitrate of Sodium	19·9	12·6	20·4
2	14 tons Farmyard Manure	11·4	9·4	10·1

plot was ascertained from the analysis of the same samples in which nitric acid was determined. The produce includes corn and straw. The nitrogen as nitric acid is that present in 27 inches from the surface.

In the above Table we really compare the quantity of nitric acid produced during two months in the field (plus residues of nitrates in certain cases), with the total nitrogen contained in the surface soil, and with the amount of previous produce on the

same plot. The figures would be more exact if we knew in every case the quantity of nitric acid lost by drainage before the samples of soil were taken for analysis, as this quantity of nitric acid has clearly to be credited to the soil or manure of the plots in question. We are, however, only able to make this correction in the case of three of the plots mentioned in the Table. It will be more convenient, therefore, to confine ourselves to the figures deduced from the actual determinations of nitric acid in the soils.*

On the permanently unmanured Plots 3 & 4, 1000 of total soil nitrogen has yielded 6·7 of nitric nitrogen; and on the unmanured Plot 16A it has yielded 6·6. On the very moderately manured Plot 6A, yielding nearly twice the produce of the unmanured land, the product in the same time has been 10·2 of nitric nitrogen per 1000 of soil nitrogen. This increased capacity for producing nitrates is shown by every plot in the field yielding an increase of produce, the lowest proportions being 8·1 per 1000 in the case of Plot 13A, and 7·6 per 1000 in the case of Plot 17A. Plot 5A, manured with ash-constituents alone, shows 9·7 per 1000; the amount of nitric acid found in this soil, judged by the evidence of the drainage-water, seems to be rather high. We have, further, an indication that with a rise in productiveness over that shown by Plot 6A we have a further rise in the facility with which soil nitrogen is oxidised; the product of 1000 of soil nitrogen on Plots 2, 7A, and 9A being 11·4, 12·9, and 12·4. The high figure shown by Plot 8A, and the still higher figure shown by 9B, are of course due to a larger residue of nitrates in the soil.

The fact indicated by the above calculations is one of great practical importance. Soil contains nitrogenous matters which nitrify with different degrees of facility. The bulk of the nitrogenous matter of soil is only capable of very slow oxidation, but a smaller proportion is far more readily converted into nitric acid. In thoroughly exhausted land the easily nitrifiable matter has to a large extent disappeared; in soil in good agricultural condition it is being continually renewed by fresh crop-residues, or by the application of organic manures. This easily nitrifiable matter constitutes a chief part of the floating capital of the soil, on which its immediate productiveness depends. The larger quantity of more inert nitrogenous matter constitutes the sunk capital which only very slowly becomes available.

* In the case of Plots 3&4, 6A, and 7A, the corrected proportion of total soil nitrogen to nitric nitrogen will be 1000 to 7·3, 10·7 and 14·0; and the corrected proportion of produce (average of 30 years) to nitric nitrogen, 1000 to 8·1, 7·6 and 7·5.

The facts shown by the other columns of Table VII. are nearly related to those just mentioned. When we see that the average of 30 years' produce of corn and straw on the unmanured plots stands to the amount of nitrogen oxidised to nitric acid in the soil as 1000 : 7·6; that on Plot 6A, with nearly double the produce, it stands as 1000 : 7·3; and on Plot 7A, with more than two and a half times the produce, as 1000 : 7·0, it is surely evident that the capacity for producing nitrates rises side by side with the increase of crop; that, in fact, the crop-residue annually left in the soil constitutes in most cases the chief material out of which nitrates are produced.* Recent crop-residues are not, however, in any case the sole source of soil nitrates; if this were so, it is clear that the figures given in the Table would be in all cases identical, while in fact the proportion of nitric acid produced per 1000 of crop decreases somewhat with each additional increment of crop. This is, however, what must naturally be expected. The nitric acid which is produced is derived partly from the old nitrogenous capital of the soil, and partly from comparatively recent crop-residues; in the case of the unmanured plots the old nitrogenous capital of the soil has the greatest proportional influence, while on the plots of heaviest produce (9A and 8A) it has least influence on the result. On Plots 2 and 9B we need hardly remark that the manure furnishes a considerable source of nitrate over and above the crop-residue.

Before leaving the results furnished by Broadbalk Field, we must look for a moment at the general relation of the nitrate contained in the subsequent drainage to that shown by analysis as existing in the soil. Taking an average of all the plots in which the composition of the subsequent drainage admits of estimation, we find that for 100 lbs. of nitrate existing in the soil in October, 60·2 lbs. have been removed in the course of 3½ months' drainage (8·2 inches), or have passed below the level of the drain-pipes. The amounts of nitrates passing into the subsoil will really be in excess of these estimates, but they are the only figures at command.

We may now pass to the determinations of nitric acid made in the soil of various plots in the Experimental Barley-field.

The manuring of the plots with which we are at present concerned, and their average produce during 30 years, 1852-81, have been already given in Table I. (p. 7). The crop of 1881 was cut on August 5 and 8, and carried on August 18. The land was then scarified, and afterwards ploughed in the beginning

* The vegetable matter resulting from dead weeds will participate with the residue of the crop in affording material for nitrification; this residue of weeds must always be included in the idea of crop-residue.

of October. Towards the end of February 1882 the land was harrowed and rolled. The samples of soil were taken between February 24 and March 7. The quantity of nitrogen as nitric acid found in the soils and subsoils of the various plots will be found in Table VIII.

TABLE VIII.—NITROGEN as NITRATES in the SOIL and SUBSOIL of various Plots in HOOS BARLEY FIELD, March 1882.

Plot.	Manuring.	Nitrogen as Nitrates in lbs. per acre. First Nine Inches.	Second Nine Inches.	Third Nine Inches.	Total Twenty-seven Inches.
		lbs.	lbs.	lbs.	lbs.
1 o.	Unmanured	5·9	4·7	5·1	15·7
2 o.	Superphosphate	6·4	5·7	6·3	18·4
3 o.	Sulphates of Alkalies	6·1	5·7	6·5	18·3
4 o.	Mixed Mineral Manure	7·5	9·7	[6·3]	23·5
	Mean of Series	6·5	6·5	6·1	19·0
1 A.	200 lbs. Ammonium-salts	6·1	8·3	7·0	21·4
2 A.	Ditto, with Superphosphate ..	7·4	11·5	8·2	27·1
3 A.	Ditto, with Sulphates of Alkalies	7·5	6·2	5·6	19·3
4 A.	Ditto, with mixed Min. Manure	8·1	5·8	8·9	22·8
	Mean of Series	7·3	8·0	7·4	22·7
1 AA.	275 lbs. Nitrate of Sodium	9·7	6·8	9·0	25·5
2 AA.	Ditto, with Superphosphate ..	7·8	10·4	8·3	26·5
3 AA.	Ditto, with Sulphates of Alkalies	7·8	6·2	8·1	22·1
4 AA.	Ditto, with mixed Min. Manure	9·4	5·7	6·2	21·3
	Mean of Series	8·7	7·3	7·9	23·9
1 C.	1000 lbs. Rape Cake	10·6	13·7	7·9	32·2
2 C.	Ditto, with Superphosphate ..	7·5	13·1	7·8	28·4
3 C.	Ditto, with Sulphates of Alkalies	10·6	11·2	9·5	31·3
4 C.	Ditto, with mixed Min. Manure	8·2	11·5	8·7	28·4
	Mean of Series	9·2	12·4	8·5	30·1
7¹	Unmanured, 1872–81 (Farmyard-manure, 1852–71)	14·8	11·8	10·9	37·5
7²	14 tons Farmyard-manure ..	18·6	14·6	10·9	44·1

The experimental difficulties referred to in the case of Broadbalk Field have proved equally great in the investigation now before us; we must be content, therefore, to seize the general features of the results, without expecting perfect accuracy in

every detail. The result of the analysis of the third depth of Plot 4 O (Table VIII.) has been rejected as plainly excessive, and the figure found for Plot 2 O substituted.

In calculating the results of the analyses into pounds per acre, the weight of fine soil in the first 9 inches of the plots of the O, A, and AA series, has been taken as 2,527,879 lbs., this being the mean weight actually found in the O, A, AA, and AAS series. The first 9 inches of soil of the plots of the C series (rape-cake) have been taken as 2,361,461 lbs., the mean weight in this series. For the first 9 inches of Plots 7[1] and 7[2] (receiving farmyard-manure) their own weights have been taken. In the case of all the subsoils, 2,593,853 lbs. have been taken as the weight of fine soil in the second depth, and 2,661,134 lbs. as the weight in the third depth, these being the mean weights of all the series above mentioned.

In considering the results of the analysis of the soils in Hoos Field, we must bear in mind the time of year at which the samples were taken. We have not to do, as in Broadbalk, chiefly with a recent production of nitrates, formed in the soil at the end of summer and early autumn, but with the nitrates left in the soil after the washing of the autumn and winter rains. The total amount of drainage passing through the 60 inch drain-gauge during the seven months from August to February was, in fact, 12·5 inches. Of the quantity of nitrates which has passed into the subsoil by drainage during this period, we get some idea from the results already given relating to Broadbalk Field (Tables V. and VI.). It naturally results from the washing out to which the soils have been subjected, that the nitrates are found more evenly distributed than was the case in the Broadbalk samples. In Broadbalk Field, omitting Plot 9B, the nitrates were distributed throughout the first, second, and third 9 inches of soil in the proportion of 100, 59, and 31. In Hoos Field the nitrates are distributed through the same three depths in the proportion of 100, 102, and 88.

There are only four plots in Hoos Field (Plots 1O, 4O, 4A, and 7[2]) where the manuring has been identical with plots in Broadbalk (Plots 3 & 4, 5A, 6A, 2); in each of these cases the nitrates found in Hoos Field are distinctly below those found in Broadbalk; a result partly due to the washing of the Hoos soils by the autumn and winter rains, but also partly to the smaller residue left in the soil by a barley-crop.

The four plots in the O series, which have received no nitrogenous manure for 30 years, give a mean of 19·0 lbs. of nitrogen as nitrates in 27 inches of soil. The entirely unmanured plot gives 15·7 lbs.

The four plots in the A series, receiving, respectively the

same ash-constituents as the four in the O series, but with 200 lbs. of ammonium-salts in addition, give a mean of 22·7 lbs. of nitrogen as nitrates in 27 inches.

The four plots in the AA series, also receiving the same ash-constituents as above, but with 275 lbs. of nitrate of sodium, give a mean of 23·9 lbs. of nitrogen as nitrates in 27 inches.

The four plots in the C series, with the same ash-constituents, and 1000 lbs. of rape-cake, give a mean of 30·1 lbs. of nitrogen as nitric acid to the same depth.

There can be no question that the nitrates found in the soils of the O series have been produced by the oxidation of the nitrogenous organic matter of the soil. In the A and AA series there can be little doubt that a large portion of the nitrates has a similar origin; Plots 1 and 3 in these series are the only ones in which it seems probable that any residue of nitrates derived from the manure can have remained in the soil through the summer. In the plots of the C series, on the other hand, a part of the nitric acid is apparently due to the rape-cake applied as manure, which only slowly decomposes in the soil. The plots which have received rape-cake for 30 years show, in fact, a higher average amount of total nitrogen in the soil than any other plots in the field, with the exception of those receiving farmyard-manure. The considerable amount of nitric acid in the plot manured with rape-cake in Broadbalk Field has been already noticed.

There is thus, notwithstanding the comparatively washed-out condition of the plots when sampled after the autumn and winter rains, still a sufficiently marked difference between the mean amount of nitrates found in the soils of the different series, to be traceable to their different conditions of manuring, and the varying amounts of crop and crop-residue. From the same cause the differences among the plots within each series are also small; but there are indications that these too are dependent on the varying conditions of manuring and growth. In series O, A, and AA, the plots 2 and 4 receiving superphosphate, which yield the largest crop and crop-residue, are those which generally contain the largest quantity of nitric acid. With more growth there would also be more evaporation; the soils after harvest would therefore be drier, in some cases considerably so, and hence it would require so much more subsequent rain to cause the same amount of passage of nitrates downwards, and the nitrates would accordingly remain in a greater proportion within the range of the soil-sampling.

Among the plots of the C (Rape-cake) series a contrary result is observed. Plots 1 and 3, with somewhat less growth, never-

theless show rather more nitrates than Plots 2 and 4; which would seem to be due to a greater residue of manure in the former plots.

The plots receiving farmyard-manure give the largest amounts of nitrates. On Plot 7[2], where 14 tons of farmyard-manure have been applied annually for 30 years, the nitrogen in the form of nitric acid amounts to 44·1 lbs. per acre to the depth of 27 inches. Of great interest, too, is the result presented by Plot 7[1]. Here 14 tons of farmyard-manure were applied for 20 years, but the land during the next 10 years was unmanured, and continually cropped with barley. The effect of the previous manuring is still abundantly shown in the barley-crop (see Table I.), and the land is found to contain 37·5 lbs. of nitrogen as nitrates, a quantity larger than on any other plot, excepting that still receiving an annual dressing of farmyard-manure.

The relation between the quantity of nitrogen as nitrates found in 27 inches of the barley soils, and the total quantity of nitrogen present in the surface-soils of the same plots, is shown in Table IX. The relation of the nitrates to the average total produce of the land is also shown.

TABLE IX.—NITROGEN as NITRATES in HOOS FIELD SOILS, March 1882, for 1000 of SOIL NITROGEN, and of AVERAGE PRODUCE.

PLOTS.	MANURING.	Nitrogen as Nitrates in Soil.		
		For 1000 of Soil Nitrogen.	For 1000 Average Produce.	
			Average Fourteen Years 1868–81.	Average Two Years 1880–1.
1 O	Unmanured	6·7	9·4	8·4
1 4 A	Ammonium-salts, with and without Minerals	8 8	5·5	5·1
1-4 AA	Nitrate of Sodium " " "	6·7	5·3	4·9
1-4 C	Rape Cake " " "	10·0	6·2	5·5
7 [2]	Farmyard-manure	9·9	7·2	6·7

The comparison between the quantity of total nitrogen in the surface-soil, and the quantity of nitrates existing in the land, is not so striking as in the case of the wheat-field, partly because in the present case the nitrates were to a considerable extent removed by drainage before the samples of soil were taken. The results, however, are in the same direction as before. Any increase in the produce of the land is attended with an increase in the amount of nitrates produced within the soil, due therefore to an increased amount of crop-residue. Where rape-cake, [illegible]

farmyard-manure is applied there is not only a nitrifiable crop-residue left in the land, but also a residue of nitrogenous organic matter from the manure, which still further adds to the quantity of nitrate produced.

The relation between the previous amount of crop and the quantity of nitrate in the soil is far less marked than in the wheat-field. This is partly owing to the comparatively washed-out condition of the barley land, but mainly to the much smaller residue left in the soil by barley than by wheat. In the wheat-field the percentage of nitrogen and carbon in the soil of each plot is plainly related to the quantity of crop annually produced. In the barley-field considerable variations in crop are attended with only small alterations in the quantity of nitrogen and carbon in the soil. The recent crop-residues being smaller in the barley-field, a larger proportion of the nitrate is due to the old nitrogenous capital of the soil, or in some cases to residues of manure. The connection between the amount of crop and the production of nitrates is best seen when reference is confined to the last two crops of the field. The relation between the results of different plots is similar to that shown in the wheat-field. (Table VII.)

3. *Nitrates in Land growing Leguminous Crops.*

Several determinations have been made of the quantity of nitrates existing in soils which have grown leguminous crops; to these we must now call attention.

In Table III. will be found determinations of nitrates in two soils in Agdell Field which had grown beans. On the fully manured rotation the bean-crop yielded 26⅝ bushels of corn; the total crop contained about 66 lbs. of nitrogen. The soil gave in the first 18 inches 20·5 lbs. of nitrogen as nitrates; the other half of the land, which was in bare fallow, yielding at the same time 48·8 lbs. On the rotation manured with superphosphate only, the produce was 7¾ bushels of corn, and the total crop contained about 26 lbs. of nitrogen. The soil yielded 10·6 lbs. of nitrogen as nitrates in 18 inches, the corresponding bare fallow containing 36·3 lbs. The bean-crops were cut on Aug. 24, the soils were sampled on Sept. 24–25, 1878. A part of the nitrates found in these soils would probably be produced in the month of August, when the rainfall was very excessive (nearly 5 inches), or in September.

In Table III. will also be found a determination of nitrates in the same field after a crop of clover in 1882. The clover was grown on part of the fully-manured rotation plot. The crop, in two cuttings, yielded 83⅔ cwts. of hay, estimated to contain

nearly 200 lbs. of nitrogen. The clover land, and the corresponding bare fallow, were sampled on September 8, before the clover land had been ploughed. The clover land contained in 27 inches 19·6 lbs. of nitrogen as nitrates, while in the soil of the corresponding bare fallow 59·9 lbs. were found.

It is clear that in each of these comparative determinations between beans and fallow, or clover and fallow, we must not assume that the crop had at command the whole quantity of nitrates found in the fallow soil, as the production of nitrates in it would be considerably favoured by the summer tillage, a condition which was, of course, wanting in the case of the cropped land. Though, however, we may not credit the crop with having assimilated the whole difference observed between the nitrates of the cropped and uncropped land, there can be no doubt that in every case a considerable quantity of nitrate has been taken up from the first 27 inches of soil, the depth to which the sampling was confined. Considerable additional quantities of nitrate would probably be obtained from the lower depths of the subsoil, especially in the case of the clover crop.

In Table IV. determinations of nitrates are given in two plots in Hoos Field, which had frequently grown leguminous crops, and which now failed to grow red clover. One plot had just grown a small crop of white clover, amounting to 24 cwts. of hay per acre; the other had just produced an enormous crop of Bokhara clover, yielding in one cutting 125½ cwts. of hay per acre, and containing about 144 lbs. of nitrogen. The samples of soils were taken on July 26–31, 1882, immediately after the removal of the crops; the sampling was carried to the depth of 54 inches. The whole amount of nitrogen as nitric acid found in this depth was 26·3 lbs. per acre in the case of the short-rooted white clover, and 8·5 lbs. per acre in the case of the deep-rooted Bokhara clover. In the first 27 inches of depth, the white-clover soil contained 13·5 lbs., and the Bokhara-clover soil only 5 lbs. In the second 27 inches, the white-clover soil contained 12·8 lbs., or nearly as much as the first, and the Bokhara-clover soil only 3·5 lbs. It is obvious that the Bokhara clover had withdrawn nitrates to the full depth examined, and it had doubtless done so to a lower depth still. We have here again evidence that a leguminous crop, and especially one having a wide distribution of roots, assimilates the nitrates of the soil; and in the case of such a plant as the Bokhara clover, a great depth of the subsoil is clearly brought under contribution.

We have one experiment yet to mention. It is well known that a clover lay is a good preparation for wheat; this is doubtless chiefly due to the gradual nitrification of the nitrogenous residue left behind by the clover. [illegible]

the different condition of land in March after a wheat and after a clover crop, will be found in Table III. (Nos. 11, 12); the comparison is, however, not perfect, as the clover land had been ploughed the preceding October, while the wheat-stubble was untouched. The clover land yielded 38·9 lbs. of nitrogen as nitrates in the first 27 inches, and the wheat land only 14·5 lbs.

The evidence relating to the amount of nitrates in the different soils seems to point to the conclusion that, in the case of cereal crops, the nitrates of the soil are a sufficient source of the nitrogen of the crops. Can the same be said with regard to beans or clover? That these crops do assimilate nitrates in considerable quantity is sufficiently established. A good crop of red clover may, however, in land in favourable condition, but without the direct application of manure, yield from seed sown in the spring of the previous year, hay containing 200 lbs. of nitrogen per acre, and also leave much nitrogenous crop-residue in the surface-soil. Again, the Bokhara clover, grown in Hoos Field, in a soil on which red clover had frequently failed, yielded, during five successive years, 1878–82, without any application of nitrogenous manure, an average of about 93 lbs. of nitrogen per acre per annum. These quantities much exceed the amounts which, according to our present knowledge, could be furnished by nitrates in the soil. Our information as to the amount of nitrates available in the lower layers of the subsoil is, however, as yet very limited. On this point it may be stated that determinations made in samples collected this year (1883) to the depth of 108 inches in the white-clover soil, have shown more than 50 lbs. of nitrogen as nitrates per acre below 45 inches of depth. On the other hand, adjoining land in fallow, which had been alternately wheat and fallow without manure for about 30 years, showed less than 20 lbs. in the corresponding layers. The question obviously arises whether leguminous crops do not find in the soil suited to their growth some other source of nitrogen than nitrates. The very large amount of nitrogen taken up by these crops would, on this supposition, be due to their possession of a power of utilising nitrogen existing in the soil in a condition of combination, as well as of distribution, not available to cereal crops.

We have now completed our account of the quantity of nitrates found at various depths, and at various seasons, in cropped land subjected to a great variety of manuring. Before concluding, we must say a few words as to the bearing of some of these results upon the important questions raised in the last section of the previous Report on Rain and Drainage.

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summer-time? Or are the nitrates passing below a certain level liable to be destroyed by chemical reduction, of which action some examples were given in the previous Report? It may well be, that in subsoils of different character, and in different conditions of saturation with water, one or other of these results may occur, but the information at present at command on the subject is very limited. A further examination of the composition of subsoils at low depths is now in progress at Rothamsted.

Summary of Results.

1. The soils of the three drain-gauges, 20, 40, and 60 inches deep, which have now remained without manure and without crop for thirteen years, have, during the last six years, yielded nitric acid in the drainage-water equal to an average of 40·2 lbs. of nitrogen per acre per annum. The production of nitrates is greatest during summer. The minimum amount in the drainage-water occurs in spring; the maximum in July, or in the first month afterwards in which considerable drainage occurs.

2. In three soils at Rothamsted, in fair agricultural condition, cultivated as bare fallow since the harvest of the previous year, 56·5, 58·8, and 59·9 lbs. of nitrogen as nitric acid per acre were found in September or October, to the depth of 27 inches. If the summer has been dry, the nitrates are near the surface; after much rain they are at a lower level. If the amount of nitrates which it is estimated have passed by drainage below 27 inches during the season of fallow (15 months) is taken into account, the total production of nitrates corresponds to about 80 lbs. of nitrogen per acre. When the soil is in a poor agricultural condition, the production of nitrates during fallow is much less.

3. In exhausted land, but left uncropped four years (Geescroft Field), only very small quantities of nitrates were found in the subsoil to a depth of 6 feet. The subsoil was, however, saturated with water, and it seems possible that a portion of the nitrates had been destroyed by chemical reduction.

4. The results relating to land growing cereal crops, receiving no excess of nitrogenous manure, show that only very small quantities of nitrates will remain in the upper layers of the soil through the summer, the crop having assimilated the nitrates formerly present. If rain follow after harvest, and especially if the land be ploughed, a considerable formation of nitrates will occur. Nitrates will continue present throughout the winter, notwithstanding loss by drainage, slow production being always in progress. In late spring or early summer, the nitrates will again disappear if the land is once more under crop.

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8. Comparing the quantity
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or of organic manure.

constituents, a mean of 23·3 lbs. Plots receiving 1000 lbs. of rape-cake, with or without ash-constituents, a mean of 30·1 lbs. The plot receiving 14 tons farmyard-manure, 44·1 lbs. The residues of the rape-cake and of the farmyard-manure added considerably to the quantity of nitrate produced. The influence of crop-residues in increasing the production of nitrate is not so marked as in the wheat-field, barley leaving a smaller residue in the soil than wheat.

11. A comparison of the quantity of nitrate found in soils cropped with beans or clover, with that found in corresponding land in bare fallow, showed that nitrates are assimilated by leguminous crops. A similar result appeared when the comparison was made between a vigorous deeply-rooted leguminous plant (Bokhara clover) and a delicate short-rooted one (white clover), the former taking more nitrate from the subsoil than the latter.

12. The quantity of nitrogen in luxuriant leguminous crops appears too great to be accounted for by the quantities of nitric acid at present recognised in soils. We have however as yet very limited information as to the quantity of nitric acid in the lower layers of the subsoil. The question remains whether leguminous crops have the power of utilising nitrogen existing in the soil in a condition of combination (as well as of distribution), not available to cereal crops?

13. The results relating to the soils in the Broadbalk Wheat-field, together with those relating to the pipe-drainage-waters, confirm the conclusion put forward in the former Report—that the estimates of loss by drainage founded on the amount of water passing through the 60-inch soil drain-gauge, and on the composition of the pipe-drainage in the wheat-field, are too low; it appearing that considerably more nitrates pass into the subsoil than such a calculation shows.

14. It is a question whether, under some circumstances, and especially if the subsoil is saturated with water, nitrates which have passed into the lower layers of the subsoil are not there destroyed by reduction; or to what extent the nitrates which are not reduced, or not finally lost by drainage, return upwards in dry weather, or are available to plants of deep-rooting habit and vigorous growth.

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